University of Alberta

The development and carbon accumulation of five peatlands along a climatic gradient in west central British Columbia, Canada

by

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ABSTRACT

This thesis represents the first inquiry into peatland development and carbon (C) accumulation along a gradient from coastal to continental climates in western North America. Five ombrotrophic, raised bogs were studied in west – central British Columbia with peat initiation primarily controlled by climatic factors coinciding with the end of the early Holocene Xerothermic Interval. In all peatlands, autogenic processes resulted in general successional sequences from minerotrophic to ombrotrophic peats, although rich fen brown mosses were absent from coastal records. Long term apparent rates of peat and C accumulation exhibited no trends along the climatic gradient and, while a concave "Clymo" pattern of cumulative peat mass with age was observed in one coastal peatland, all other sites displayed linear curves. Ashless peat bulk density was influenced by depth in the peat core, peat composition, and peatland development. Specifically, peatlands developing as floating mats showed distinctive patterns of bulk density with depth.

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While reading is a huge part of graduate school, it was really the discussion of these published concepts, that I found most interesting, particularly when coupled with my own observations from the field. These discussions served, not only to solidify and define ecological concepts but also to inspire me, and reinforce why I am so interested in peatland ecology in the first place. Ilka Bauer, Merritt Turetsky, Dave Beilman and Steve Robinson all contributed (whether they know it or not) but I would most especially like to thank Ilka Bauer for the seemingly endless discussions of peatland ecology we had in the lab, the field, the truck, and the bar. Ilka has been an excellent friend and mentor throughout, always there for me to run things by and to seriously consider my occasionally wild ideas without condescension. I would also like to thank all other members of the Vitt lab who were there both as friends, and to "talk shop" (Nat Cleavitt, Jennifer Doubt, Suzanne Mills, Linda Halsey, Zicheng Yu, Catherine LaFarge-England, Tracey Mattock, Martina Krieger, Sandi Vitt, Erica Heinlen, and Jeff Heinlen). Erica and Jeff, in particular were great friends and running companions both in Edmonton and Carobondale.

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LIST OF SYMBOLS AND ABBREVIATIONS

α	the level of significance used in statistical testing, reflecting the probability of a type I error
AA	identifier for the University of Arizona AMS dating laboratory
ABS	Acrylonitrile – Butadiene – Styrene
AD	Anno Domini, which translates as "in the year of our lord" and refers to the Christian dating system in popular usage. This system is more convenient for very recent dates as BP (before present) dates would be negative in years more recent than AD 1950.
AMS	accelerator mass spectrometry (a method used in radiocarbon dating)
B	Bog (a peat type)
BD	bulk density
BD_a	Ashless bulk density
BD_{ic}	the ashless bulk density of increment i in core c, where there are n increments
BGCZ	Biogeoclimatic Zone
C	carbon
^{14}C	radiocarbon (the unstable C isotope which undergoes radioactive decay and is used in radiocarbon dating)
^{14}C yr BP	radiocarbon years before 1950 (refers to conventional, uncalibrated radiocarbon dates)
Ca	calcium
cal. yr BP	calendar years before 1950 (refers to calibrated radiocarbon dates)
Cl	chlorine
CO_2	carbon dioxide
CWH	Coastal Western Hemlock (a BGCZ)
CWHvh2	the very wet hypermaritime subzone of the CWH BGCZ

ERF	Extreme – Rich Fen (a peat type)
HAWT	height of the peatland surface above the water table
HF	Herbaceous Fen (a peat type)
ICH	Interior Cedar – Hemlock (a BGCZ)
ICHmc2 = ICHg3	the moist, cold subzone of the ICH BGCZ
K	potassium
Kcorr	ionic conductivity corrected for temperature and hydrogen ion concentration
LORCA	long term apparent rate of carbon accumulation
M_c	the cumulative dry peat mass of core c
Mg	magnesium
MRF	Moderate – Rich Fen (a peat type)
Na	sodium
NMDS	Non-Metric Multidimensional Scaling
OFB	Oceanic Fen / Bog (a peat type)
OPF	Oceanic Poor Fen (a peat type)
PF	Poor Fen (a peat type)
PFB	Poor Fen / Bog (a peat type)
pH	the hydrogen ion activity measured on a logarithmic scale
σ	standard deviation
SBS	Sub – Boreal Spruce (a BGCZ)
SBSdk	the dry, cool subzone of the SBS BGCZ
SE	standard error
SO_4	sulphate
TO	identifier for the Isotrace AMS dating laboratory at the University of Toronto
w_{ic}	the thickness of increment i in core c

CHAPTER 1

General Introduction

General Background and International Relevance

Peatlands are waterlogged terrestrial ecosystems where, due to anaerobic conditions, rates of organic matter production exceed rates of decomposition resulting in accumulation of organic matter on the landscape. Under the Canadian System of Wetland Classification peatlands are defined as those areas where accumulated soil organic matter has reached a depth of 40 cm (Zoltai 1988). Canada is thought to contain the second highest peatland area of any country in the world (Gorham 1991).

Because peat is composed of partially decayed organic matter, peatland growth represents a transfer of atmospheric carbon (C) to the soil and with the retreat of ice sheets following the Wisconsin Glaciation in the late Pleistocene and early Holocene (Clague 1984; Dyke and Prest 1987) Canadian peatlands have been functioning as a net C sink (Vitt et al. 2000; Gajewski et al. 2001). Currently, peatlands represent approximately one third of the global soil C stocks (Gorham 1991), which is equivalent to 60% of the CO_2 – C currently stored in the atmosphere (Nilsson et al. 2001).

Peatland Classification

The classification of peatlands is based on a number of inter-related factors. Fundamentally, the classification is hydrological with ombrotrophic systems (bogs) influenced only by precipitation – derived water, and minerotrophic systems (fens) influenced to varying degrees by water that has been in contact with mineral soil (Vitt 1994). It is difficult to measure the relative input of water from these different sources, and classification in the field is based on the reflection of that hydrology in the vegetation and surface water chemistry of peatlands. The fen gradient from poor fens through moderate-rich fens to extreme rich fens demonstrates an increasing influence of minerotrophic groundwater that results in an increasing number of rich fen indicator plant species (DuRietz 1949). The ombrotrophy – minerotrophy gradient is also correlated with surface water chemistry as minerotrophic systems exhibit higher pH values and total ionic content than ombrotrophic systems (Vitt 1994). Vegetationally and chemically the main distinction among peatland types lies between the alkaline, brown moss (mostly Amblystegiaceae) dominated rich fens and the acidic, *Sphagnum* – dominated bogs and poor fens (Vitt 1994).

Autogenic Succession

Hydrology is also important in peatland development, as peat accumulation raises the peatland surface farther above the mineral groundwater table. Thus, the fundamental process of autogenic succession in peatlands commonly follows the minerotrophy – ombrotrophy gradient with extreme-rich fens gradually developing into bogs over time (Kuhry et al. 1993; Janssens et al. 1992; Nicholson and Vitt 1990). The relationship of *Sphagnum* species to pH is particularly important to peatland development because of their ability to further acidify the system through the exchange of cations for hydrogen ions (Clymo 1963, 1987; Craigie and Maass 1966; Gorham et al. 1987). Once *Sphagnum* becomes established in a peatland, there is a period of rapid transition in surface water chemistry from pHs above 6.0 to pHs less than 5.5 (Vitt and Kuhry 1992; Gorham et al. 1984). This transition is also reflected in the peatland vegetation and accounts for the distinct floristic differences between poor fens and bogs, which are *Sphagnum* – dominated, and moderate-rich and extreme-rich fens, which are dominated by brown mosses (Vitt 1994).

Peatland development tends to initiate via one of two general patterns although both can, and often do, occur in the same peatland. Terrestrialization occurs when a lake, or shallow water body, is colonized by wetland vegetation, typically encroaching along the margins and eventually covering and filling in the basin with peat (Moore and Bellamy 1974; Vitt and Slack 1975; Klinger 1996b). In such a sequence, the initial colonizers are in direct contact with the limnogenous ground water and comprise a fen community, the type (rich or poor fen) depending on the chemistry of the lake water (Vitt and Slack 1975). As the mat thickens, and fills in the basin, the peat surface is able to rise above the lake (groundwater) level and is influenced to a greater degree by precipitation, becoming a poor fen and finally, when peat accumulates such that the surface vegetation loses contact with the minerotrophic groundwater, an ombrotrophic bog (Vitt and Slack 1975). In this process the peatland surface becomes drier as the lake basin is filled with peat.

Paludification is a process through which a 'drier' surface becomes wetter as relatively dry mineral soil is colonized by peat forming vegetation (Gore 1983). This commonly happens at the margin of existing peatlands where the peat acts as a sponge, pulling the water table upwards under the peat deposit and "swamps" neighbouring areas (Heinselman 1963; Moore and Bellamy 1974; Frenzel 1983; Klinger 1996b). In the humid climate of northern coastal British Columbia and south-eastern Alaska, paludification is thought to result from the formation of placic horizons (Ugolini and Mann 1979; Banner et al. 1986; Klinger 1996a) or simply through the slow build-up of forest organic matter (Zack 1950; Lawrence 1958; Reiners et al. 1971; Banner et al. 1986) impeding drainage and allowing *Sphagnum* species to colonize the soil, beginning peat formation. Placic horizons are subsurface soil layers characterized by cemented deposits of Fe or Mn leached from upper horizons, forming pans that resist water movement (Brady and Weil 1996).

Although both terrestrialization and paludification have been described above as autogenic, they may also be influenced by allogenic factors. In particular, changes in the water table caused by factors such as diversion of watercourses or changes in the regional climate may impact on peatland development causing deviations from the typical autogenic successional sequence (e.g. Glaser et al. 1990).

Climatic Influences

Climate, specifically, influences both the presence and abundance of peatlands on the landscape (Halsey et al. 1998; Halsey et al. 1997; Kuhry and Zoltai 1994; Vitt 1994). Studies of peatlands along climatic gradients in northwestern Europe have shown that distance from the coast is the most important factor in structuring species composition (Malmer 1985, 1986). Distance from the coast is also an important factor structuring peatland vegetation in eastern North America (Damman 1977; Johnson 1977; Glaser and Janssens 1986; Glaser 1992; Anderson and Davis 1997). In peatlands of south-eastern Alaska, Sjörs (1985) observed a steep oceanic to continental gradient, and Gignac (Gignac et al. 1991) found climate to be the most important factor in structuring the ecotopes of peatland bryophyte species in western Canada (British Columbia, Alberta, Saskatchewan and Manitoba).

Carbon Accumulation

Long term peat accumulation is often described in terms of a conceptually simple model originally proposed by Clymo in 1984. The so-called Clymo model considers peat accumulation in terms of an aerobic surface peat layer (the acrotelm) and an underlying, anaerobic peat layer (the catotelm). Organic matter produced at the peatland surface is partially decomposed under the aerobic conditions of the acrotelm before being transferred to the catotelm where decomposition continues at a much slower rate. Given a constant input of peat from the acrotelm to the catotelm and a constant rate of decay within the catotelm, Clymo (1984, 1998) predicts a concave relationship between cumulative peat mass and age (Figure 1-1). While constant rates of input and decay seem unlikely given autogenic succession and changing climate conditions, using only profiles dominated by *Sphagnum* peat Clymo successfully described peat accumulation profiles in oceanic raised bogs of western Europe (Clymo 1984). It is important to consider that this model was developed for oceanic raised bogs and is recommended for use only when four criteria are met (Clymo et al. 1998):

1. there are eight or more ^{14}C dates available from a single profile,
2. the peat profile was collected near the centre of the peatland,
3. the bulk density was measured throughout the profile, and
4. a fairly homogeneous botanical composition is present throughout the profile.

When these criteria are relaxed, the concave "Clymo" relationship was shown to be widespread in southern Finland (Clymo 1998) but has been less successfully supported for fens and peatlands in northern Finland, boreal Canada, and Siberia (Clymo et al. 1998; Yu et al. 2000; Turunen et al. 2001).

The Peatlands of Coastal Western British Columbia

On the Pacific Coast of British Columbia, there are areas where peatlands cover from 50 to 75% of the terrain (Banner et al. 1988; Banner et al. 1986), making them the dominant ecosystem in these regions. These areas comprise what is known as the Northcoast Pacific Oceanic Wetland Subregion (Banner et al. 1988) that is the northern part of the Pacific Oceanic Wetland Region, occupying the coastal areas north from approximately 50°45' latitude into southeastern Alaska. The Southcoast Pacific Oceanic Wetland

Subregion and the Temperate Wetland Region occupy the remaining area within which coastal wetlands occur (Banner et al. 1986).

One of the first to study these Pacific coast peatlands was George B. Rigg from the University of Washington, who published a number of papers in the early to mid – 1900s. These papers were generally descriptive, characterizing the flora of coastal peatlands, mostly bogs, ranging from Oregon to Alaska. He also described the bog structure (Rigg 1922, 1925, 1937; Rigg and Richardson 1934, 1938) and speculated on developmental sequences and requirements (Rigg 1917, 1919, 1922, 1925; Rigg and Richardson 1934, 1938).

Since this time, a number of scientists have focused on the "muskeg" and bog-forest complexes of northwestern British Columbia and southeastern Alaska. These studies have expanded on the raised bogs of this area studied by Rigg (1917, 1925, and 1937) with Banner et al. (1987) describing the bogs as being basin, flat, shore, sloping, and blanket types. The coastal vegetation is described as being divisible into four site units: upland productive forest, upland scrub forest, bog woodland, and open blanket bog (Banner et al. 1987). In a later paper (Banner et al. 1986) the bog areas are further divided into bog forest, bog woodland, and open blanket bogs, the latter of which can be then broken into shallow minerotrophic blanket bogs, and deep ombrotrophic blanket bogs. These shallow minerotrophic blanket bogs are likely, actually, poor fens as the definition of fens used (Banner et al. 1986) includes only non-*Sphagnum* peat areas. This definition would exclude poor fens as defined by DuRietz (1949) and Sjörs (1950), placing the true, *Sphagnum*-dominated, poor fens in with the bogs for Banner's classification. This concurs with Vitt et al. (1990) who identified the majority of the peatlands in the hyperoceanic region near Prince Rupert as being soligenous poor fens, occurring on shallow peat.

The development of northwestern coast peatlands, and successional relationships with the forested areas were also studied by a number of researchers, with conflicting opinions. Many scientists (Klinger 1996a; Lawrence 1958; Reiners et al. 1971; Ugolini and Mann 1979; Zack 1950) described bogs as the successional climax of the region, developing from forested terrain. This is thought to occur through organic matter build-up causing moisture to be retained in the forest floor, allowing for *Sphagnum* colonization, which increases the moisture of the area, eventually killing the trees (paludification). This view is contradicted (Stephens et al. 1970) with examples of forests that have developed over top of sedge or *Sphagnum* peat layers. Neiland (1971) addressed this when she referred to the tension between tendencies towards better drainage and forests, and the tendencies towards poorer drainage and bog growth. Banner also addressed this problem, stating that no uni-directional successional trend can be generalized (Banner et al. 1987) and that the zonal vegetation is dynamic and may represent an oscillating climax between bog to forest, and forest to bog encroachment (Banner et al. 1986).

The peatlands of coastal, western British Columbia have also been identified as unique in the world and are different from those in Fennoscandia and both east coast and continental North America. Sjörs (1985) concluded, when writing about the mires of southern Alaska, that "These communities merit their own phytosociological classification and should not be included in systems developed in the west of Europe." One of the major differences given by Sjörs (1985) is the abundance of trees on the Alaskan mires when compared with those of Atlantic Europe. It is also the tree species that differentiate these coastal mires from their North American counterparts. In the continental North American mires, black spruce (*Picea mariana*) and tamarack (*Larix laricina*) are typical species (Zoltai et al. 1988). These two species are absent from the coastal peatlands, where shore pine (*Pinus contorta* var. *contorta*), western red-cedar (*Thuja plicata*), yellow-cedar (*Chamaecyparis nootkatensis*) and western hemlock (*Tsuga heterophylla*) are the most common tree species (Vitt et al. 1990). The species of *Sphagnum* were also found to differ between coastal and continental mires (Gignac and Vitt 1990) with *S. austinii, S. pacificum, S. palustre, S. papillosum, S. rubellum*, and *S. tenellum* restricted to oceanic areas, and *S. teres, S. angustifolium, S. russowii, S. squarrosum*, and *S. jensenii* showing strong tendencies towards continental peatlands. The same trend was shown in another study (Gignac et al. 1991) with *S. tenellum, S. austinii, S. rubellum*, and *S. papillosum* restricted to hyperoceanic, oceanic and suboceanic areas and *S. riparium*, and *S. jensenii* to continental and subcontinental mires.

The peatlands of east coast North America also differ in a number of ways from their west coast counterparts. One striking difference is the abundance of bogs on the east coast. On the west coast the peatlands are predominantly poor fens (Vitt et al. 1990) while on the east coast there is a zone of ombrogenous bogs stretching from central Maine, north to southern Labrador (Damman 1986). In this region, blanket bogs are described as being found only in the extreme coastal regions of Newfoundland, the coastal plain of New Brunswick, and the Cape Breton Highlands (Glaser and Janssens 1986). The remainder of these East Coast bogs are described as being plateau bogs (Glaser and Janssens 1996). This is in agreement with studies in Nova Scotia (Damman and Dowhan 1981), Maine (Damman 1977) and New Brunswick (Damman 1977) where plateau bogs are described as having steep side-slopes, rising from a well developed lagg, and leveling off in the centre to a flat, poorly drained, treeless surface. No plateau bogs, such as these, have been described on the West Coast. Another distinctive feature is the lack of trees on the East Coast bogs. These bogs are described as untreed or mostly untreed (Damman 1977; Damman and Dowhan 1981; Glaser and Janssens 1986; Wells 1981) with black spruce present in the cases where trees do occur. As mentioned earlier, black spruce is absent from West Coast peatlands, and is used as an indicator of continentality in British Columbia mires. In Maine, Anderson and Davis (1997), using a TWINSPAN analysis on plant community data, differentiated coastal peatlands from those farther inland, finding a number of species that were restricted to coastal or subcoastal peatlands.

Past research in Pacific Coast peatlands has, thus, established that these ecosystems are unique in the world, and can be characterized by their flora. It has also been shown that bryophyte species assemblages vary along a climatic gradient from the coast to the interior of western North America (Gignac and Vitt 1990; Gignac et al. 1991).

Objectives and Structure of Thesis

It has been shown that the peatlands of Canada store a significant amount of C and respond to climatic influences. Given the prevalence and global uniqueness of peatlands in north – coastal British Columbia, coupled with the contrasting developmental patterns observed in these peatlands, it is important to understand how palaeoclimatic conditions have influenced the peatland development in this region. It is also of interest, how any developmental patterns, and trends in C storage, vary along a gradient from coastal to continental climates in western British Columbian peatlands.

In western British Columbia the steep coastal mountain ranges provide few opportunities to study peatlands in non – alpine or subalpine transitional regions between the coastal and continental climates. In west-central British Columbia, the Skeena / Bulkley river system carves a broad valley through the Coast Mountain Range and provides a region influenced by climates transitional between the coastal climates to the west and the continental climates to the east. This transitional climatic zone is unique in British Columbia and this study focuses on five peatlands distributed along the Skeena and Bulkley valleys.

Specifically, Chapter 2 presents a primarily palaeoecological analysis of peatland development in west-central British Columbia. Differences in peatland development and surface vegetation are compared between three climate zones ranging from coastal to continental. Macrofossil assemblages are interpreted in terms of surface peatland communities and the surface water pH and height above water table of the peatland surface are reconstructed using the bryophyte macrofossil records and a surface calibration dataset (Gignac et al. 1991). The balance between autogenic and allogenic successional patterns is explored through the comparison with published palaeoclimate records, as are peatland initiation patterns (paludification versus terrestrialization).

Chapter three represents a preliminary inquiry into peatland C accumulation along the same gradient from coastal to continental climates in west – central British Columbia. Specifically, this chapter focuses on patterns of C accumulation and factors influencing the peat bulk density (as a proxy for peat C content). Long term apparent rates of C accumulation are compared, along with the "Clymo" C accumulation curves. Peat type and macrofossil categories, derived from the Chapter 2 analysis are coupled with depth in the peat core to explain trends in the peat bulk density.

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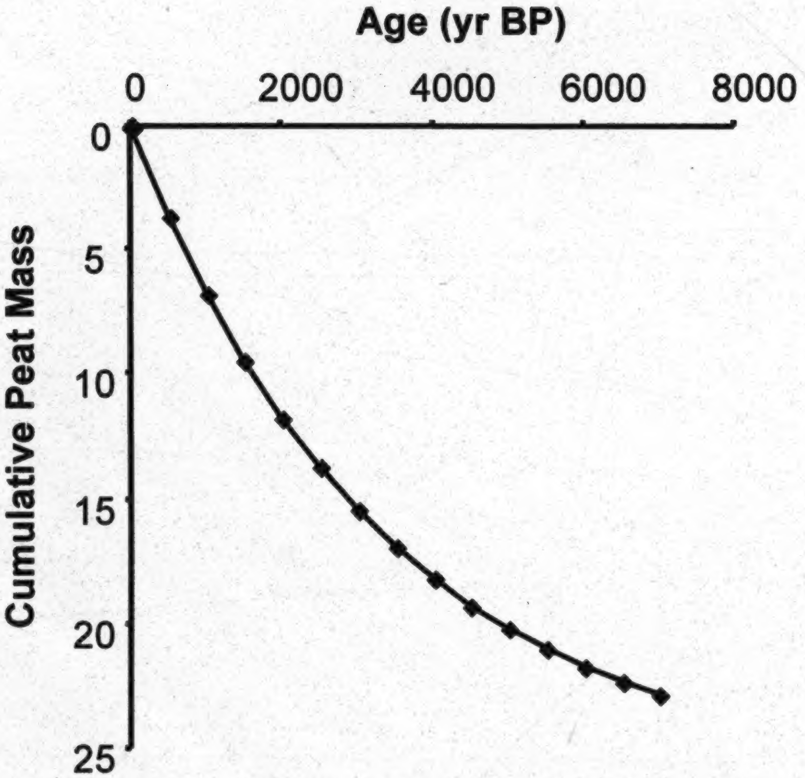

Figure 1-1: A sample "Clymo" curve demonstrating the concave relationship between peat age (t) and the cumulative mass of peat below the surface (M), given a constant rate of organic matter input to the catotelm (p) and a constant rate of decay (α). The equation form follows $X = p^{-\alpha t,}$ which implies that the rate of mass lost over time is proportional to the amount of material remaining (Clymo 1984).

CHAPTER 2

Peatland development along a climatic gradient in west-central British Columbia, Canada

INTRODUCTION

Peatlands are waterlogged ecosystems where, due to anaerobic conditions, rates of organic matter production exceed rates of decomposition resulting in accumulation of organic matter on the landscape. In north coastal British Columbia, high mean annual precipitation (2951 mm; Klinka et al. 1991) results in a near constant supply of water encouraging the development of peatlands not only in basins but across the landscape, covering from 51 to 75% of the terrain (Banner et al. 1986; Banner et al. 1988). In contrast, peatlands found in the mid Boreal climate of interior British Columbia, are influenced by a much lower mean annual precipitation (467 mm; Meidinger et al. 1991) and are thus restricted to basins and shallow slopes, occupying less than 5% of the terrain (Zoltai et al. 1988). In west-central British Columbia, the Skeena / Bulkley river system carves a broad valley through the Coast Mountain Range, allowing for a zone of vegetation transitional between the coastal and the continental regions with a mean annual precipitation of 614 mm (Environment Canada 2002).

In this paper, four peatland types are recognized: bogs, poor fens, moderate-rich fens and extreme-rich fens. The classification of peatlands into these types is based on a number of inter-related factors. Fundamentally, the classification is hydrological with ombrotrophic systems (bogs) influenced only by precipitation, and minerotrophic systems (fens) influenced to varying degrees by water that has been in contact with mineral soil (Vitt 1994). Practically, it is difficult to measure the relative input of water from these different sources, and classification in the field is often based on the vegetation and surface water chemistry of peatlands. The fen gradient from poor fens through to extreme rich fens demonstrates an increasing influence of minerotrophic groundwater that results in an increasing number of rich fen indicator plant species (DuRietz 1949). The ombrotrophy – minerotrophy gradient is also correlated with surface water chemistry as minerotrophic systems exhibit higher pH values and total ionic content than ombrotrophic systems (Vitt 1994).

Hydrology is also important in peatland development, as peat accumulation raises the peatland surface above the mineral groundwater table. Thus, the fundamental process of autogenic succession in peatlands generally follows the minerotrophy – ombrotrophy gradient with rich fens gradually developing into bogs over time (Nicholson and Vitt

1990; Janssens et al. 1992; Kuhry et al. 1993). The relationship of *Sphagnum* species to pH is particularly important to peatland development because of their well-known ability to further acidify the system through the exchange of cations for hydrogen ions (Clymo 1963, 1987; Craigie and Maass 1966; Gorham et al. 1987). Once *Sphagnum* becomes established in a peatland, there is a period of rapid transition in surface water chemistry from pHs above 6.0 to pHs less than 5.5 (Vitt and Kuhry 1992; Gorham et al. 1984). This transition is also reflected in the peatland vegetation and accounts for the distinct floristic differences between poor fens and bogs, that are *Sphagnum* – dominated, and moderate-rich and extreme-rich fens, that are dominated by brown mosses (Vitt 1994).

Peatland development tends to initiate via one of two general patterns although both can, and often do, occur in the same peatland. Terrestrialization occurs when a lake, or shallow water body, is colonized by wetland vegetation, typically encroaching along the margins and eventually covering and filling in the basin with peat (Moore and Bellamy 1974; Vitt and Slack 1975; Klinger 1996b). In such a sequence, the initial colonizers are in direct contact with the limnogenous ground water and comprise a fen community, the type (rich or poor fen) depending on the chemistry of the lake water (Vitt and Slack 1975). As the mat thickens, and fills in the basin, the peat surface is able to rise above the lake water (groundwater) level and is influenced to a greater degree by the precipitation, becoming a poor fen and finally, when peat accumulates such that the surface vegetation loses contact with the minerotrophic groundwater, an ombrotrophic bog (Vitt and Slack 1975). In this process the peatland surface becomes drier as the lake basin is filled with peat.

Paludification is a process through which a ‘drier’ surface becomes wetter as relatively dry mineral soil is colonized by peat forming vegetation (Gore 1983). This commonly happens at the margin of existing peatlands where the peat acts as a sponge, pulling the water table upwards under the peat deposit and “swamps” neighbouring areas (Heinselman 1963; Moore and Bellamy 1974; Frenzel 1983; Klinger 1996b). In the humid climate of northern coastal British Columbia and south-eastern Alaska, paludification is thought to result from the formation of placic horizons (Ugolini and Mann 1979; Banner et al. 1986; Klinger 1996a) or simply through the slow build-up of forest organic matter (Zack 1950; Lawrence 1958; Reiners et al. 1971; Banner et al. 1986) impeding drainage and allowing *Sphagnum* species to colonize the soil, initiating peat formation.

Although both terrestrialization and paludification have been described as autogenic, they may also be influenced by allogenic factors. In particular, changes in the water table caused by factors such as diversion of watercourses or changes in the regional climate may impact on peatland development causing deviations from the typical autogenic successional sequence (e.g. Glaser et al. 1990). Climate, specifically, influences both the presence and abundance of peatlands on the landscape (Kuhry and Zoltai 1994; Vitt 1994; Halsey et al. 1997; Halsey et al. 1998). Studies of peatlands along climatic gradients in northwestern Europe have shown that distance from the coast is the most important factor in structuring species composition (Malmer 1985, 1986). Distance from the coast is also an important factor structuring peatland vegetation in eastern North America (Damman 1977; Johnson 1977; Glaser and Janssens 1986; Glaser 1992; Anderson and Davis 1997). In peatlands of south-eastern Alaska, Sjörs (1985) observed a steep oceanic to continental gradient, and Gignac (Gignac et al. 1991) found climate to be the most important factor in structuring the ecotopes of peatland bryophyte species in western Canada (British Columbia, Alberta, Saskatchewan and Manitoba).

Because peatlands form from vegetation deposited, in situ, under waterlogged conditions one method allowing peatland development to be studied in detail is through the identification of plant macrofossils preserved as layers of successive communities in the peat deposits (Vitt and Kuhry 1992). The bryophyte macrofossil record, specifically, has been used in continental Canada to provide detailed records of community changes, which have been used to study peatland development (Kubiw et al. 1989; Nicholson and Vitt 1990; Kuhry et al. 1992; Kuhry et al. 1993). In addition, known preferences of bryophyte species can be used to reconstruct environmental conditions of the palaeo-communities such as pH and height of the peatland surface above the water table (Janssens et al. 1992; Kuhry et al. 1993).

Understanding how climate has influenced past peatland development is particularly relevant when considering peatland responses to future climate changes. Along the Northwest Coast of British Columbia, where peatlands occupy such a dominant position on the landscape, changes in peatland vegetation would have a substantial impact on the regional ecology. Consequently, this study examines peatland development through the use of macrofossils and palaeoenvironmental reconstruction of the surface water pH and depth of the water table from the peatland surface. Specifically, surface vegetation and peat cores from five ombrotrophic, raised bogs along a gradient from coastal to continental climates in west – central British Columbia will be examined:

1. To confirm that the surface peatland vegetation varies along the climatic gradient;
2. To determine if, despite the selection of ombrotrophic sites, the peatland surface water chemistry also varies along the climatic gradient;
3. To determine if the peatlands occupying the region of transitional climates are truly intermediate, or if they show greater vegetative, and developmental affinities to either the coastal or continental zone peatlands;
4. Using the macrofossil record, to determine if differences in the surface vegetation reflect entirely different developmental sequences or if some peat types, and successional patterns are common across climate regions;
5. Using the macrofossil record, radiocarbon dating, and reconstructed pH and height above the water table (HAWT) to determine the relative importance of autogenic and allogenic factors in peatland development. In particular, peatland responses to palaeoclimate conditions will be explored.

STUDY AREA

The climatic gradient studied in west – central British Columbia encompasses three Biogeoclimatic Zones (BGCZs) reflecting the regions of coastal climate, continental climate, and the transitional climate that results from an intermingling of the continental air masses and moist, pacific air penetrating inland through wide valleys in the Coast ranges.

Five peatlands were located along this gradient, with Butze Rapids Bog and Green River Bog near Prince Rupert in the coastal zone, Powerline Bog and Highway Bog near New Hazelton in the transitional zone, and Adamson Bog near Telkwa in the continental zone

(Figure 2-1). In order to maintain developmental consistency across regions, all selected sites were ombrotrophic, raised bogs.

The coastal climate is expressed in the Coastal Western Hemlock (CWH) BGCZ. The CWH climate is characterized as cool mesothermal with cool summers and mild winters (Figure 2-2A) (Pojar et al. 1991). Both coastal sites (Butze Rapids and Green River Bogs) are located in the very wet hypermaritime (CWHvh2) subzone, which has a mean annual precipitation of 2951 mm and a mean annual temperature of 8.2°C (Klinka et al. 1991). The peatlands studied in this zone are dominated by dwarf *Pinus contorta* var. *contorta* and *Thuja plicata* trees with *Sphagnum austinii*, *Racomitrium lanuginosum*, and *Cladina* spp. in the ground layer. Surrounding upland vegetation is characterized by *Chamaecyparis nootkatensis*, *Thuja plicata*, and *Tsuga heterophylla*, with a typical understory of *Gaultheria shallon*, *Blechnum spicant*, *Hylocomium splendens*, and *Rhytidiadelphus loreus* (Pojar et al. 1991).

The region of transitional climate is recognized by the Interior Cedar – Hemlock (ICH) BGCZ (Figure 2-1). This zone is characterized by warm, moist summers with cool, wet autumns and cold winters (Figure 2-2B) (Haeussler et al. 1985). The two sites in this zone (Powerline and Highway Bogs) are located in the moist, cold subzone (ICHmc2, formerly the ICHg3) near New Hazelton, and experience a rain shadow effect. The closest long-term weather station (Hazelton Temleham; 55°12'N, 127°44'W, 121.9 m above sea level) located approximately 5 km to the southwest indicates a mean annual precipitation of 614 mm and a mean annual temperature of 4.8°C (Environment Canada 2002). The regional climax vegetation is forests of *Tsuga heterophylla*, and *Thuja plicata*, with *Hylocomium splendens*, *Pleurozium schreberi*, and *Ptilium crista-castrensis*, although seral stands of *Populus tremuloides*, *Betula papyrifera*, *Pinus contorta* var. *latifolia* with *Corylus cornuta* commonly dominate the upland vegetation (Haeussler et al. 1985). The two peatlands in the ICH are dominated by *Picea mariana*, with a dense shrub layer of *Ledum groenlandicum* and ground layers of *Pleurozium schreberi* and *Sphagnum fuscum*.

Continental climate occurs along the transect in the Sub – Boreal Spruce (SBS) BGCZ, which is characterized by long, cold and relatively dry but snowy winters with mild, moist and short summers (Figure 2-2C) (Pojar et al. 1984). The single site in this zone

(Adamson Bog) is found in the dry, cool (SBSdk) subzone where the mean annual precipitation is 467 mm and the mean annual temperature is 3.1°C (Meidinger et al. 1991). In this region, the dominant upland tree species are *Picea glauca* x *engelmannii*, *Pinus contorta* var. *latifolia*, *Populus tremuloides* and *Populus balsamifera* with *Rosa acicularis*, *Lathyrus nevadensis* and *Pleurozium schreberi* common in the understory (Meidinger et al. 1991). The one peatland studied in this zone was dominated by a *Picea mariana* forest with an understory of *Ledum groenlandicum* and a ground layer of *Sphagnum angustifolium*, and *Sphagnum fuscum*.

Not only does this transect encompass a range of climates, but the surficial geology is also variable. Butze Rapids bog is formed directly in a bedrock depression but all other sites are underlain by Quaternary mineral deposits formed over the regional bedrock. Green River Bog lies in a depression in an alluvial terrace of sands and gravels (Clague 1984). Powerline Bog also lies in a shallow channel scar of a sandy alluvial plain, while Highway Bog developed in a depression in the ground moraine, overlain by a sandy glaciofluvial veneer (Clague 1984). Adamson Bog lies in a depression in the glacial drift covering the floor of the Bulkley Valley (Leach 1907; Armstrong 1944). Despite variations in bedrock, all formations are comprised of generally acidic rock types (Sutherland Brown 1960; Hutchinson 1982; Gottesfeld 1985).

METHODS

Field Methods

In each peatland, 2-3 peat cores were extracted in the deepest portions (as determined by probe transects), using a modified Macaulay peat auger with an inside diameter of 5 cm. Core sections were stored in 5 cm diameter half sections of 0.5 m to 2 m plastic ABS (Acrylonitrile-Butadiene-Styrene) pipe and wrapped with plastic (Sunspun®) film for transport from the field. Cores A and B were taken from Butze Rapids Bog, C, D, and E from Green River Bog, F and G from Highway Bog, H and I from Powerline Bog and cores J, K, and L from Adamson Bog.

The surface vegetation was recorded in 50 m^2 circular relevés (3.99 m radius) centred on each core site. Percentage cover values were estimated for each species in the relevé. Species names follow Douglas et al. (1998) for vascular plants, Anderson (1990) for Sphagna, Anderson et al. (1990) for other mosses, Paton (1999) for hepatics and Goward (1999) for lichens. Raw surface vegetation data can be found in Appendix I.

Water Chemistry

The pits remaining from core sampling were allowed to fill with water and pH was determined onsite using a Fisher pH/TEMP 119 pH meter. Two water chemistry samples were collected in acid-washed polyethylene bottles. The first sample was filtered (1.0 micron Gelman A/E glass fibre filter paper) within 12 hours of collection and kept in a cooler for transport to the laboratory where Ca^{2+}, Mg^{+}, Na^{+}, K^{+}, SO_4^{2-}, and Cl^{-} concentrations were determined using a DIONEX ion chromatograph for the anions and a Perkin – Elmer Atomic Absorption Spectrometer 3300 for the cations. The second sample was frozen and conductivity was measured in the lab using a CDM 83 conductivity meter. Conductivity was standardized to 20°C (Gardiner and Dackombe 1983) and corrected for hydrogen ions (Sjörs 1950). Raw water chemistry data can be found in Appendix II.

Peat Core Analysis

The deepest peat core from each bog was sub-sampled every 10 cm, or more frequently with changes in the peat stratigraphy. At each depth, samples for macrofossil and physical analysis were extracted from semi-frozen peat, using a brass cork borer with an inner diameter of 1.8 cm. To prevent contamination from coring equipment, both ends of the peat sample were removed, resulting in samples of volumes ranging from 1.5 - 5.3 cm^3.

The macrofossil samples were analyzed under a dissecting microscope with frequencies estimated as volume percentages from cover estimates of each taxon present. Samples were not sieved and fine organic debris was recorded as a taxon indicative of a difference in peat type and / or decomposition. When degree of decomposition or absence of key features prevented identification of macrofossils to species, taxa were recorded as broad groups such as "woody roots" or to groups of species such as "section Acutifolia *Sphagnum*". Appendix III lists macrofossil categories and their identifying features.

Basal ^{14}C AMS (accelerator mass spectrometry) dates were obtained for each core with the base of peat initiation defined as the lowest point in the core where organic matter accounted for at least 70% of the peat dry weight (Korhola 1994). After preliminary analysis of the macrofossil samples, important transitions within the cores were also dated. The timing of other stratigraphic transitions was estimated by linear interpolation between available ^{14}C dates. To maintain consistency with existing regional chronology, uncalibrated ^{14}C dates are used throughout this chapter. Although only conventional (uncalibrated) ^{14}C dates are used in the text of this paper, in Table 2-1 both conventional and calibrated dates are provided so that results of this study can be more easily compared with chronologies using calendar years rather than radiocarbon years. The dates were converted to calendar years using the standard calibration data set IntCal04 (Reimer et al. 2004) in CALIB (Stuiver and Reimer 1993) rev. 5.0. A single value was determined for each sample using the probability distribution to determine a weighted average following the recommendation of Telford et al. (2004).

Statistical Methods

Ordination

In order to elucidate patterns of species composition along the oceanic - continental gradient, and over time within each peatland, Non-Metric Multidimensional Scaling (NMDS) ordinations were performed on the surface vegetation data, the macrofossil data from each peat core, and the combined macrofossil dataset. NMDS is a non-parametric ordination technique that positions sample objects in ordination space based on the rank order of the intersample dissimilarities (Fasham 1977). Because NMDS assumes neither linear nor unimodal response models, it escapes many of the distortions present in eigenvector methods (Fasham 1977; Prentice 1980; Kenkel and Orloci 1986; Minchin 1987). The Sorensen (Bray-Curtis) distance (Faith et al. 1987) was used as a measure of ecological dissimilarity in the NMDS ordinations. Environmental variables were not explicitly used to structure the ordination, but were overlain on the diagram based on correlations with the ordination axes (McCune and Mefford 1999). In macrofossil ordinations, samples containing greater than 50% mineral soil were excluded from the ordinations. All ordinations were carried out in PC-ORD (McCune and Mefford 1999).

Correlations

Correlation of surface vegetation species with environmental variables was carried out using SPSS for Windows Release 11.01 (SPSS Inc. 2001).

Zonation

To simplify the changes in species composition throughout the cores, constrained incremental sum of squares cluster analysis (Grimm 1987) was used to define zones of similar species composition within each core. This method minimizes the total sum of squares variation within clusters and is constrained such that only stratigraphically adjacent samples can be merged. The squared chord distance was used as a measure of compositional dissimilarity (Prentice 1980; Overpeck et al. 1985) within the ZONE software package (Juggins 1991).

Indicator Species Analysis

Indicator species analysis (Dufrêne and Legendre 1997) was used to identify characteristic species for each zone. This method combines the relative abundance of a species with its relative frequency of occurrence in the zones, producing a maximum value (100%) when all individuals of a species are found in a single zone and when the species occurs in all samples of that zone (Dufrêne and Legendre 1997). Significance of each species, as an indicator, was tested for the zone in which it reached its maximum value, using a randomization procedure (Dufrêne and Legendre 1997; McCune and Mefford 1999). Reported species have an indicator value that is ≥ 25% and is significant ($\alpha = 0.05$) in the zone it which it reaches its maximum indicator value (Dufrêne and Legendre 1997).

Palaeoenvironmental Reconstructions

Surface water pH and height of the peatland surface above the water table were reconstructed using the bryophyte component of the macrofossil record and a calibration dataset (Gignac et al. 1991) containing 30 species in 159 plots distributed between latitudes of 52° and 56° N and longitudes of 111° and 132° W. The height above water table (HAWT) was reconstructed by weighted averaging – partial least squares (WA-PLS) (ter Braak and Juggins 1993) and pH by weighted averaging (WA), without a deshrinking regression (Kuhry et al. 1993). The HAWT reconstruction was carried out using WAPLS version 1.5 (Juggins and ter Braak 2001).

RESULTS

Ordination of Surface Vegetation and Environmental Parameters

Ordination of the surface vegetation data was optimal (McCune and Mefford 1999) at a 2-dimensional solution with a stress of 5.77, accounting for 83.5% of the total variation in the dataset. There is clear separation between the coastal sites and both the interior and transitional sites, although the interior and transitional sites are closely associated with each other (Figure 2-3). There is little species overlap between the coastal sites and the interior / transitional sites, with two distinct species groups at either end of the gradient (Figure 2-4). This main gradient of variation coincides with distance from the coast, as well as to conductivity, calcium, magnesium, and potassium concentrations, which increase away from the coast, and sodium and sulphate concentrations, which increase weakly towards the coast (Figures 2-3 & 2-4). Distance from the coast is significantly ($\alpha = 0.05$) correlated to species of every vegetative layer, but all significant correlations are negative (Table 2-2), indicating that species with higher abundances towards coast are more sensitive to the climatic gradient represented by the distance from the coast.

Basal Dates

Butze Rapids and Green River Bogs began peat accumulation 7610 ± 90 and 7870 ± 100 ^{14}C yr BP respectively. Powerline and Highway Bogs initiated peat accumulation at

8830 ± 80 and 8590 ± 70 ^{14}C yr BP, while Adamson Bog began accumulating peat 7930 ± 70 ^{14}C yr BP (Table 2-1).

Detailed Stratigraphic Descriptions

Zonation of the macrofossil data resulted in three to eight zones per core, which were each classified into a general peatland type based primarily on the classifications of Gignac et al. (1991) using the indicator species of each zone and confirming the classifications using other taxa present. Because many species are common to both bogs and poor fens it was often not possible to distinguish between bogs and poor fen peat types using only the macrofossil record. Where ambiguity occurred in surficial macrofossil zones, peat types were more specifically identified as bogs, relying on classification of the surface vegetation. Complete macrofossil diagrams can be found in Appendix IV to supplement the following overview of each zone.

Coastal Region

Core A (Butze Rapids Bog)

Zone A-3: Herbaceous Fen (7610 – 1776 ^{14}C yr BP) is dominated by debris, herbaceous remains, woody roots, Pteridophytae / *Equisetum* roots and low but consistent levels of *Sphagnum austinii*, section acutifolia *Sphagnum* and *Sphagnum magellanicum / centrale*. *Hylocomium splendens*, wood, dicot leaf fragments and charcoal are also occasionally present. The significant indicator species for this zone are Pteridophytae / *Equisetum* roots, herbaceous remains, charcoal, *Hylocomium splendens*, wood, and debris (Table 2-3).

Zone A-2: Poor Fen (1776 – 628 ^{14}C yr BP) is dominated by section acutifolia *Sphagnum*, herbaceous remains, woody roots, with low amounts of debris and occasional occurrences of *Sphagnum papillosum* and *Sphagnum magellanicum / centrale*. Charcoal is only present in one sample of this zone and *Sphagnum austinii* and *Pinus contorta* leaf remains are present in the upper portions of the zone. The significant indicator species of this zone are section acutifolia *Sphagnum* and herbaceous remains (Table 2-3).

Zone A-1: Oceanic Bog (628^{14}C yr BP – present) is dominated by *Sphagnum austinii*, with low abundances of debris and herbaceous remains. Section acutifolia *Sphagnum* is present but in lower abundances than in zone A-2, and the surface samples of this zone contain the liverwort species *Cephalozia loittlesbergi*, *Kurzia* cf. *trichoclados* and *Mylia anomala*. The only significant indicator species of this zone is *Sphagnum austinii* (Table 2-3).

Core C (Green River Bog)

Zone C-8: Poor Fen (7470 – 5678 ^{14}C yr BP) is dominated by debris and herbaceous remains, with Pteridophytae / *Equisetum* roots increasing towards the top of the zone. *Sphagnum* sp. was also found in this zone and identified as belonging to section acutifolia, where it was possible to make a distinction beyond genus. Woody remains, including woody roots and ericaceous shrubs such as *Empetrum nigrum*, and *Ledum groenlandicum*, were also present in the zone, although the only significant indicator species were debris and Pteridophytae / *Equisetum* roots (Table 2-3).

Zone C-7: Poor Fen (5678 – 4984 ^{14}C yr BP) contains *Pleurozium schreberi*, and low abundances of *Sphagnum papillosum*, in addition to those taxa present in zone C-8. The significant indicator species for this zone are section acutifolia *Sphagnum* and Pteridophytae / *Equisetum* roots (Table 2-3).

Zone C-6: Poor Fen (4984 – 3250 ^{14}C yr BP) has a very similar species composition to both C-7 and C-8. Debris is present in lower abundances than in zones C-7 and C-8, along with *Sphagnum* belonging to both sections acutifolia and cuspidata. Dicot leaves are also present, along with woody roots and the occasional sample containing *Ledum groenlandicum*, *Empetrum nigrum*, *Hylocomium splendens*, or *Pleurozium schreberi*. Pteridophytae / *Equisetum* roots are found towards the base of the zone, and the only significant indicator species is section cuspidata *Sphagnum* (Table 2-3).

Zone C-5: Oceanic Poor Fen (3250 – 2990 ^{14}C yr BP) is dominated by *Sphagnum papillosum*, which is the indicator species for the zone (Table 2-3). Herbaceous remains are also present in this zone, but at relatively low levels.

Zone C-4: Oceanic Poor Fen (2990 – 1521 ^{14}C yr BP) contains taxa similar to zone C-6, without section cuspidata *Sphagnum*, and with occasional *Sphagnum papillosum*, and *Pinus contorta* leaves. There are no significant indicator species for this zone as all the dominant species, particularly herbaceous remains and section acutifolia *Sphagnum*, are prevalent throughout the core.

Zone C-3: Oceanic Fen / Bog (1521 – 917 ^{14}C yr BP). *Racomitrium lanuginosum* is the only significant indicator species of the zone (Table 2-3) and is the dominant taxon in the zone. *Pleurozium schreberi*, *Empetrum nigrum*, and herbaceous remains also occur.

Zone C-2: Herbaceous Fen (917 – 313 ^{14}C yr BP) is dominated by herbaceous remains and debris, with very low amounts of *Sphagnum austinii*, section acutifolia *Sphagnum*, and woody roots. The only significant indicator species for this zone are herbaceous remains (Table 2-3).

Zone C-1: Oceanic Bog (313 ^{14}C yr BP – present) is dominated by *Sphagnum austinii*, with small amounts of section acutifolia *Sphagnum*, lichens, and the liverworts *Cephalozia loitlesbergi*, *Calypogeia sphagnicola*, *Kurzia* cf. *trichoclados,* and *Mylia anomala*. Because there is only one sample in this zone indicator species analysis could not be performed.

Transitional Region

Core G (Highway Bog)

Zone G-8: Mineral (undated) is the basal zone of Core G and consists of a layer of mineral soil overlain by a layer of marl, containing small amounts of debris, Pteridophytae / *Equisetum* roots, *Daphnia* sp., and mollusc remains. Both marl and mineral soil are significant indicators for this zone (Table 2-3).

Zone G-7: Lake / Shallow Water (>8590 – 8169 ^{14}C yr BP). The basal date of Core G (8590 ± 70 yr BP) (Table 2-2) lies in the middle of this zone, above the samples containing mollusc shells. Small amounts of *Chara* sp. and Pteridophytae / *Equisetum* roots occur throughout the zone but G-7 is dominated by debris, with mollusc shells and *Daphnia* sp. remains in the lower half. The significant indicator species are *Chara* sp., debris and mollusc shells (Table 2-3).

Zone G-6: Extreme-rich Fen [wet phase] (8169 – 7179 ^{14}C yr BP) is dominated by *Scorpidium scorpioides*, with low abundances of *Calliergon trifarium*, *Campylium stellatum*, debris, herbaceous remains, dicot leaves, and Pteridophytae / *Equisetum* roots. The significant indicator species for this zone are *Scorpidium scorpioides*, and *Calliergon trifarium* (Table 2-3).

Zone G-5: Extreme-rich Fen [dry phase] (7179 – 6374 ^{14}C yr BP) is dominated by debris and herbaceous remains, with *Calliergon giganteum*, *Calliergon trifarium*, *Campylium stellatum*, *Limprichtia revolvens*, *Hamatocaulis vernicosus*, *Meesia triquetra*, *Scorpidium scorpioides*, *Bryum* sp., *Carex* section Limosae roots, and *Betula* sp. seeds also present. The significant indicator species for this zone are *Bryum* sp., *Calliergon trifarium*, *Campylium stellatum*, *Meesia triquetra*, *Betula* sp.seeds, *Carex section* Limosae roots, and herbaceous remains (Table 2-3).

Zone G-4: Moderate-rich Fen (6374 – 5128 ^{14}C yr BP) contains *Sphagnum teres*, and *Tomentypnum nitens* as significant indicator species (Table 2-3). The zone is dominated at the top by *Sphagnum teres*, and at the bottom by *Tomentypnum nitens*. Pteridophytae / *Equisetum* roots, *Carex* section Limosae roots, *Pinus contorta* leaves, wood and woody roots are also present in the zone.

Zone G-3: Herbaceous Fen (5128 – 83 ^{14}C yr BP) is dominated by debris and herbaceous remains with low abundances of wood and woody roots. The basal two samples are anomalous, containing *Sphagnum warnstorfii*, and *Calliergon trifarium*, while the top sample is dominated by section cuspidata *Sphagnum*. Low abundances of *Sphagnum magellanicum* and section cuspidata *Sphagnum* occur throughout the zone. The significant indicator species of this zone are debris and herbaceous remains (Table 2-3).

Zone G-2: Poor Fen / Bog (83 – 0 ^{14}C yr BP) is dominated by *Sphagnum magellanicum*, with woody roots and low amounts of debris. The significant indicator species for this zone is *Sphagnum magellanicum* (Table 2-3).

Zone G-1: Bog (0 ^{14}C yr BP – present) is dominated by *Pleurozium schreberi*, *Ledum groenlandicum*, woody roots, dicot leaves, and small amounts of *Sphagnum* sp. The significant indicator species for this zone are *Ledum groenlandicum*, and *Pleurozium schreberi* (Table 2-3).

Core I (Powerline Bog)

Zone I-5: Mineral (undated) is a mineral soil zone, containing small amounts of Pteridophytae / *Equisetum* roots, debris, marl, *Scorpidium scorpioides*, and *Sphagnum* sp. The significant indicator species for this zone are mineral soil and Pteridophytae / *Equisetum* roots (Table 2-3).

Zone I-4: Extreme-rich Fen (>8830 – 5684 ^{14}C yr BP) is dominated by debris, herbaceous remains, and woody roots, with Pteridophytae / *Equisetum* roots, *Scorpidium scorpioides*, *Calliergon giganteum*, and *Calliergon trifarium* occurring through out the zone with varying abundances. Also present, in zone I-4, are *Sphagnum fuscum*, marl, *Picea mariana* and *Pinus contorta* needles, dicot leaves, Cyperaceae seeds, *Chara* sp., *Limprichtia revolvens*, *Sphagnum teres*, *Polytrichum strictum*, *Aulacomnium palustre* and *Betula* sp. seeds. The significant indicator species for this zone are *Calliergon giganteum*, *Scorpidium scorpioides*, and herbaceous remains (Table 2-3).

Zone I-3: Bog (5864 – 4135 ^{14}C yr BP) is dominated by *Sphagnum fuscum* with low levels of debris and herbaceous remains. *Polytrichum strictum*, *Pleurozium schreberi*, woody roots, dicot leaves, and *Carex* section Limosae roots are also present in this zone. The only significant indicator species for zone I-3 is *Sphagnum fuscum* (Table 2-3).

Zone I-2: Herbaceous Fen (4135 – 3057 ^{14}C yr BP) is dominated by herbaceous remains, woody roots, and debris, with charcoal, *Carex* section Limosae roots, and

Tsuga heterophylla needles also present. *Sphagnum teres* dominates the uppermost sample while a small amount of *Sphagnum fuscum* is present in the lowermost sample of the zone. Herbaceous remains and woody roots are the only two significant indicator species in the zone (Table 2-3).

Zone I-1: Bog (3057 ^{14}C yr BP – present) is dominated by *Sphagnum fuscum* with woody roots, debris, and low levels of herbaceous remains. *Pinus contorta*, *Picea mariana*, and dicot leaves are also present in this zone. One sample, at a depth of 35.5cm likely indicates the presence of fire in the peatland, with low levels of *Sphagnum fuscum* and the presence of *Polytrichum strictum*, *Carex* section Limosae roots, charcoal and relatively high debris values. This one sample is not typical of the entire zone, however, and the significant indicators for zone I-1 are *Sphagnum fuscum*, and woody roots (Table 2-3).

Continental Region

Core L (Adamson Bog)

Zone L-6: Mineral (undated) consists almost entirely of mineral soil with only trace (<0.5%) amounts of herbaceous remains present. This zone contains only one sample so significant indicator species could not be determined.

Zone L-5: Lake / Shallow Water (7770 + ^{14}C yr BP). This zone is dominated by marl and mollusc shells, with low amounts of debris and herbaceous remains. *Chara* sp., *Daphnia* sp., and Pteridophytae / *Equisetum* roots are also present and the significant indicator species for zone L-5 are marl and mollusc shells (Table 2-3).

Zone L-4: Extreme-rich Herbaceous Fen (7770 – 6385 ^{14}C yr BP) is dominated by herbaceous remains, marl and debris, with low amounts of *Daphnia* sp., *Chara* sp., *Bryum pseudotriquetrum*, dicot leaves, and wood. Mollusc shells are present in the lowermost sample of the zone. The presence of substantial marl (33%) is indicative of an extreme rich fen (Vitt et al. 1993). The only significant indicator species in zone L-4 is herbaceous remains (Table 2-3).

Zone L-3: Moderate-rich Fen (6385 – 3890 ^{14}C yr BP) is dominated by herbaceous remains, debris, Pteridophytae / *Equisetum* roots and infrequent occurrence of Cyperaceae and *Betula* sp. seeds, dicot leaves, and the bryophyte species: *Bryum pseudotriquetrum*, *Tomentypnum nitens*, *Drepanocladus aduncus*, *Drepanocladus* sensu lato (concept of Wynne 1944, including *Limprichtia revolvens* and *Hamatocaulis vernicosus*), and *Calliergon giganteum*. The significant indicator species for zone L-3 are *Drepanocladus aduncus*, Pteridophytae / *Equisetum* roots, and herbaceous remains (Table 2-3).

Zone L-2: Poor Fen (3890 – 800 ^{14}C yr BP) is dominated by debris, woody roots, herbaceous remains, and contains small amounts of Pteridophytae / *Equisetum* roots. Section acutifolia *Sphagnum*, dicot leaves, *Picea mariana*, charcoal, and Cyperaceae seeds were also present in this zone. The significant indicator species of zone L-2 are debris and woody roots (Table 2-3).

Zone L-1: Bog (800 ^{14}C yr BP – present) is dominated by *Sphagnum angustifolium*, *Pleurozium schreberi*, *Ptilium crista-castrensis*, *Picea mariana*, woody roots, and *Ledum groenlandicum*. The significant indicator species for this zone are *Sphagnum angustifolium*, *Pleurozium schreberi*, *Picea mariana*, *Ptilium crista-castrensis*, and woody roots (Table 2-3).

Ordination of Macrofossils by Stratigraphic Zones and Peat Types

Ordination of the macrofossil samples resulted in optimal 2-dimensional solutions for all cores except for core C, which was optimal in 3 dimensions. Stress ranged from 9.01 and 10.82 for cores C and A respectively, through to 13.90, 14.43, and 15.06 for cores L, I and G. The distinction of zones on the core ordinations, and the grouping of zones with similar peat types supports both the statistical zonation technique and the more subjective peat type classifications.

In Core A the three zones are clearly differentiated vegetationally with no overlap between zones in the ordination (Figure 2-5A).

In Core C, the zones are not clearly differentiated vegetationally, except for the oceanic bog zone, C-1, which was so different that it obscured detail of other variations within the core and was excluded from the ordination (Figure 2-5B) in order to differentiate other samples. With zone C-1 removed, the oceanic fen / bog zone, C-3, is the only distinct group in the ordination (Figure 2-5B), separated from all other zones which are various types of herbaceous or poor fens.

Core G shows clear distinction between zones although the bog and poor fen / bog zones (G-1 and G-2) are closely associated and are the only two zones to overlap in distribution on the ordination diagram (Figure 2-5C). Despite mineral-dominated samples being excluded from the ordination, one sample from the mineral zone, G-8, remains in the ordination because it is dominated by marl and not mineral soil.

In core I the two bog zones (I-1 and I-3) are closely associated with each other and are distinct from other zones with the exception of three sites in zone 1 (Figure 2-5D) which are characterized by high debris and lack of *Sphagnum fuscum* remains. The herbaceous zone (I-2) is also closely associated with the extreme-rich fen zone (I-4) (Figure 2-5D), both being characterized by high debris and herbaceous matter. Zone I-5 is not present in the ordination because all samples were dominated by mineral soil.

The zones of core L are well separated in the NMDS ordination, showing a progression from the surface bog zone (L-1) at the base of the diagram to the lowest, lake zone (L-5) in the upper right quadrant (Figure 2-5E). Zone L-6 is not included in the ordination because the only sample in the zone was dominated by mineral soil.

Palaeoenvironmental Reconstructions

Stochastic Variability

Reconstructions of both pH and HAWT display inherent stochastic variability (Figures 2-6 & 2-7). This variability is attributable to two sources. Firstly, macrofossil samples are inherently small, representing a peatland surface area of less than 1 cm^2, thus introducing very small scale spatial variability when trying to characterize average conditions for a community as a whole. Secondly, uncertainties in macrofossil identification result in the grouping of species and, therefore, decrease precision of the reconstruction.

pH

In the two coastal cores, pH has been fairly constant with cores A and C not differing significantly in average [H^+] ($\alpha = 0.05$) and all zones having average pHs ranging from 4.8 to 5.3 (Figure 2-6). The two transitional cores, G and I, and the interior core, L, display an abrupt decrease in pH partway through their profiles (Figure 2-6). In core G this decrease occurs at the base of G-3 near the transition from moderate-rich fen to herbaceous fen. In core I, the decrease lies between I-3 and I-4 where the peat changes from extreme-rich fen to bog. In core L, the lack of bryophytes in the macrofossil record make the pH reconstruction less complete and the depth of pH change less precise, although it does occur somewhere between zones L-2 and L-3, where vegetation changes from moderate-rich fen to poor fen.

Peatland Surface Height Above Water Table

Similar trends are seen with reconstruction of the height above the water table although the stochastic variability is greater than for reconstructed pH. Both of the coastal cores, A and C, show no discernable trend over time (Figure 2-7). In the transitional and interior cores there is, again, a point of transition as the height above water table shows an abrupt increase at the same depths as the decrease in pH occurred (Figures 2-6 & 2-7).

Ordination of All Sites: the relative importance of peat types versus climate zones

When all core samples are combined in a single NMDS ordination, an optimal 2-dimensional solution results, with a stress of 21.65.

Lake sediments are quite distinct, forming a group in the upper left quadrant, while fen peat types are central in the ordination with much overlap between herbaceous, moderate-rich and extreme-rich fen types (Figure 2-8A). Although samples dominated by mineral soil were excluded from this ordination, a single marl – dominated sample, from the mineral peat type underlying the lake zone in core G, is found closely associated with these lake sediments. Bog, and poor fen peat types occupy the lower and right regions of the ordination with oceanic peat types occurring specifically in the lower left quadrant with the general poor fen peat type (Figure 2-8A).

When the location of individual peat cores is considered on the ordination, it can be seen that the two coastal cores (A and C) are found dominating the lower left quadrant while the remaining cores intermix throughout the rest of the ordination diagram (Figure 2-8B). Portions of cores I and L are distinct due to occurrences of specific peat types associated with those cores. Portions of core I, contain the majority of the bog peat type, while much of the lake peat type is found in core L (Figure 2-8B).

DISCUSSION

Relationship of Peatland Vegetation to Environmental Gradients

Surface Vegetation

Ecological niches of peatland species are generally described in terms of pH, HAWT, and climatic factors (Gignac et al. 1991; Vitt 1994; Gignac et al. 2004). In this study, the climatic gradient was isolated since pH and topographic differences were minimized by site selection. Peatlands were controlled for the ombrotrophy – minerotrophy gradient by selecting only ombrotrophic (low pH), raised bogs. Surface vegetation was sampled in large plots to include local microtopographic variations, thus avoiding complications of the hummock – hollow gradient in surface vegetation data.

As intended, the surface vegetation varies, primarily, along the climatic gradient represented by the distance from the ocean (Figures 2-3 & 2-4; Table 2-2). The ionic concentrations of the peatland surface water also vary with vegetation gradient and distance from the ocean (Figures 2-3 & 2-4), likely due to changes in the precipitation chemistry. Coastal precipitation has a higher sodium concentration because of sea salt inputs (Junge and Werby 1958; McColl et al. 1982; Malmer et al. 1992; Blew and Edmonds 1995) but a lower concentration of all other ions, due to the dilution effect with increased precipitation towards the coast (Malmer et al. 1992; Blew and Edmonds 1995).

The ordination of sites along this climatic gradient (Figures 2-3 & 2-4) indicates that the peatlands influenced by hyperoceanic coastal climate are vegetatively distinct from both the interior peatlands, influenced by continental climate, and from the peatlands influenced by transitional climate. Species found to the left of the ordination diagram (Figure 2-4) and associated with the coastal sites, include those known to be characteristic of coastal peatlands such as *Sphagnum austinii* (Gignac and Vitt 1990), *Pinus contorta* var. *contorta*, and *Thuja plicata* (Banner et al. 1986). Species found to the right of the ordination (Figure 2-4), which are associated with the interior and transitional sites, and greater distance from the coast, include many of those species typical of continental peatlands such as *Picea mariana*, *Ledum groenlandicum*, *Rubus chamaemorus* (Zoltai et al. 1988) and *Sphagnum angustifolium* (Zotlai et al. 1988; Gignac and Vitt 1990; Gignac et al. 1991).

Palaeovegetation

In the ordination of macrofossil samples from all the cores (Figure 2-8), peat types are more tightly grouped than individual cores. Peat types are distinguished primarily based on position along the ombrotrophic – minerotrophic gradient while peat cores are representative of the climate zones in which they occur. The close association of samples of the same general peat type despite their occurrence in different cores demonstrates that the ombrotrophic – minerotrophic gradient is more important in structuring the vegetative communities than is the climate zone in which the peatland developed. This said, the three peat types unique to the coastal zone do have a different distribution, on the ordination, from the other samples indicating that climatic conditions have influenced the type of vegetation communities formed during peatland development.

It can also be seen that the oceanic peat types are closely linked with poor fen peat (Figure 2-8), perhaps indicating a similarity in water chemistry as the vast amount of precipitation in the oceanic region (over four times that of the transitional and continental climate regions) may prevent *Sphagnum* species from acidifying their environment to the same degree as would be seen in ombrotrophic sites with lower precipitation levels. The continuous inflow of precipitation creates a constant flow of water through the coastal bogs, similar to the water flow through fens, although without having been in contact with mineral soil. This continuous water flow means that any H^+ ions released into the water are quickly lost from the peatland and *Sphagnum* spp. are limited in their acidification ability by how fast they can grow and produce cation exchange sites able to release more H^+ ions into the water (Clymo 1987).

Peatland Development

Successional Sequences

Both coastal sites were initiated by paludification with poor fen/ herbaceous fen peat developing over mineral soil or bedrock. One of the transitional sites (Powerline Bog) also developed via paludification with a wet, extreme-rich fen developing over the mineral substrate. In contrast, the other transitional site and the interior site developed by terrestrialization, forming extreme-rich fen peat over aquatic peat. In all the peat cores, there is evidence of a prevailing direction of succession from minerotrophy towards ombrotrophy. In the coastal cores this sequence begins as poor fens develop into bogs while in the interior and transitional zones the sequence is longer, beginning with extreme-rich fens and progressing though moderate-rich fens and poor fens (in two of the three cores), and finally to bogs (Figures 2-9 to 2-12). This trend from minerotrophy to ombrotrophy is expected from autogenic succession without any 'help' from climate change as peat accumulation gradually causes the peatland surface to be isolated from the minerotrophic groundwater influence.

The most notable difference among peatland types lies between the *Sphagnum* – dominated systems (poor fens and bogs) and the brown moss dominated systems (moderate-rich and extreme-rich fens) (Vitt 1994). In the macrofossil analysis this vegetation difference is obscured by the ambiguous herbaceous material, which can occur in both poor and rich fens (Figure 2-8). In the pH and HAWT reconstructions of interior and transitional zone peatlands, pH abruptly decreases and HAWT abruptly increases as peatlands change from rich fens to poor fens or bogs (Figures 2-6 & 2-7). This distinctive transition does not occur in the coastal zone cores since peatlands initiate with pHs generally less than 5.5 (Figure 2-6) as poor fens or herbaceous poor fens. The coastal peatlands show a much more subtle autogenic successional sequence with clear changes in peatland vegetation, particularly in core A (Figure 2-5A), but very little, if any, changes in pH and HAWT (Figures 2-6 & 2-7). This is likely due to the generally acidic bedrock (Hutchinson 1982) causing even minerotrophic water sources to have low pHs, and a large amount of regional precipitation, which has a very dilute ion content, preventing rich fens from developing in most situations. It is certainly true that most peatlands in the oceanic region are bogs or poor fens (Gignac and Vitt 1990; Vitt et al. 1990) with brown moss species absent or rare in the oceanic region (Gignac et al. 1991). The distribution of *Scorpidium scorpioides* in North America (Miller 1980) also indicates an absence of extreme – rich fens in the oceanic zone. In the interior and transitional cores, however, the transition from high pH, low HAWT rich fens to low pH, high HAWT poor fens and bogs provides a clear distinction between developmental stages of the peatlands that can be dated and compared to regional climate records to see if, and how, a changing climate has influenced the timing of this important transitional stage.

Correspondence with Palaeoclimate Conditions

Peatland Initiation

Peatland initiation seems to have been more strongly controlled by climatic processes than subsequent successional pathways. The coastal peatlands have basal peat dates of 7610 and 7870 ^{14}C yr BP, corresponding to the end of the Early Holocene Xerothermic Interval (Mathewes and Heusser 1981) at approximately 7000 ^{14}C yr BP (Hebda 1995). At this point, precipitation increased and temperature cooled slightly, but stayed above present levels, in regions all along the coast from southern British Columbia (Heusser et al. 1985), to northern Vancouver Island (Hebda 1983), the Queen Charlotte Islands (Hebda 1995) and south-eastern Alaska (Heusser et al. 1985; Hansen and Engstrom 1996).

The dates of 7610 ± 90 and 7870 ± 100 ^{14}C yr BP (Table 2-1) may be slightly earlier than expected, especially given that Banner et al. (1983) indicate that in the Prince Rupert region the Early Holocene Xerothermic Interval did not end until 6000 - 7000 ^{14}C yr BP.

The dating of climatic intervals is, however, somewhat imprecise, not only because of the time it takes vegetation to respond to climatic changes, but also because of the many other local factors that influence the vegetation on which the dating is being based. A number of studies from the Pacific Coast do date the Xerothermic Interval as ending earlier, and more in accordance with peat initiation dates presented in this study. The end of the Early Holocene Xerothermic Interval is reported as 7600 ^{14}C yr BP in the Malaspina Glacier district of Alaska (Peteet 1986), 7500 ^{14}C yr BP at Marion Lake in southwestern BC (Mathewes and Heusser 1981), 8100 ^{14}C yr BP in the southern Coastal Mountains of BC (Clague et al. 1992) and as 8000 ^{14}C yr BP in western Washington State (Heusser et al. 1980).

The interior and transitional sites initiated somewhat earlier than the coastal sites at 7930 ± 130, 8590 ± 70, and 8830 ± 80 ^{14}C yr BP (Table 2-1). Because two of these sites initiated over lake peat, the limited moisture of the Xerothermic Interval was not an inhibitory condition and, likely, aided in reducing the lake level and encouraging wetland vegetation. Of the two 'lake' sites, the interior site developed later, presumably because it occupies a larger basin and, thus, took a longer time to terrestrialize. The oldest site (Core I) did not develop over a lake and most likely developed as the Xerothermic Interval dried up a shallow marsh, possibly drying up a shallow inlet stream and stabilizing the water flow in the basin. It is also possible that other factors caused a stabilization of the drainage patterns in the area and allowed peat formation to begin. It has been shown that debris flows occurred throughout the Holocene along nearby Chicago Creek, changing the flow channel and influencing sedimentation in Seeley Lake (Gottesfeld et al. 1991). Although neither Powerline nor Highway Bog are located in the Chicago Creek drainage it is likely that similar events were also occurring in the neighbouring drainage.

Peatland Development

In transitional and interior sites the fundamental transition from rich fens to poor fens or bogs occurs at approximately 4000 ^{14}C yr BP and is concurrent with the end of the mesothermic interval of Holocene climate in British Columbia (Hebda 1995). The timing of this climatic change has been very variable throughout British Columbia and climate records are sparse in the study area. As such, the few nearby sites only correlate very roughly with the timing observed in this study. In the Prince Rupert region, near to the coastal sites, there is a possible cooling and wetting to present climate conditions at approximately 3200 ^{14}C yr BP (Banner et al. 1983; Hebda 1995) although the transition to modern climatic conditions is postulated to have occurred from 5500 – 4000 ^{14}C yr BP in the Queen Charlotte Islands (Hebda 1995). Near the transitional sites at Seeley Lake, a cooling and wetting trend occurred at 4700 ^{14}C yr BP (Gottesfeld et al. 1991) and further south at Heckmann Pass (Figure 2-1), on the eastern side of the coast mountain ranges, the climate dried to modern conditions at 3800 ^{14}C yr BP (Hebda 1995). Data are even more scarce in the vicinity of the interior site and there is only one Holocene climatic record for the SBS Biogeoclimatic zone in BC (Hebda 1995). This record, from Pantage Lake (Figure 2-1) near Quesnel, indicates climate cooling to the present levels at about 5000 ^{14}C yr BP (Hebda 1995).

These palaeoclimate records indicate that the climate was becoming cooler and wetter at about 4000 ^{14}C yr BP, except possibly at Heckmann Pass where it is proposed that the climate became drier. This trend appears to be in opposition to the general lowering of the water table and decrease in pH observed at that time in the peat cores of this study. This indicates that if climate change did have any influence on peatland development in the sites investigated, that effect was overpowered by the autogenic processes already underway. Autogenic processes appear dominant in one coastal peatland (Butze Rapids Bog), where all documented palaeoclimate changes occur in the basal herbaceous fen zone (A-3) before the more recent transitions to poor fen peat types begin at approximately 1176 yBP (Figure 2-9). In the other coastal peatland, correlation with palaeoclimate is evident where local cooling and moistening of the climate occurs coincidentally with the transition from the poor fen zone C-6 to the oceanic poor fen zone C-5 (Figure 2-9). This transition is notable because it reflects the abrupt increase in *Sphagnum papillosum*, a species preferring a higher water table than the *Sphagnum* species found in the lower poor fen zone (Gignac et al. 1991), and is likely a response to a rise in the regional groundwater table, due to a wetter climate.

It is also quite possible that the moistening of the climate caused a rise in regional groundwater tables that can be seen as a delay in the autogenic successional processes. An example of this hindrance to the autogenic successional trend caused by a moistening of the climate can be seen in both transitional zone peatlands. In zone G-4 of Highway Bog the reconstructed pH decreases to a value of 5.7 (Figure 2-6) indicating a transitional stage between rich and poor fens (Vitt and Kuhry 1992). This zone occurred from 6374 to 5128 ^{14}C yr BP, before the proposed wetting trend in the region at 4700 ^{14}C yr BP (Gottesfeld et al. 1991; Figure 2-10). In the lower portion of G-3 an abrupt increase in pH is then indicated as rich fen species of *Calliergon giganteum* and *Sphagnum warnstorfii* occur, albeit in low abundances. This recurrence of rich fen species from 5128 to 4222 ^{14}C yr BP is roughly coincident with the regional wetting trend dated at 4700 ^{14}C yr BP (Gottesfeld et al. 1991) and is consistent with a rise of the regional water table at a time when transitional species were occurring and peatland vegetation was highly sensitive to slight changes in water chemistry and depth to the groundwater table. It can be seen, from the pH reconstruction, that autogenic succession took over and poor fen vegetation was established after about 4222 ^{14}C yr BP (Figure 2-10). In Poweline Bog, a herbaceous fen zone (I-2), interrupts two bog zones (I-1 and I-3) at 4135 ^{14}C yr BP indicating a decrease in the HAWT (Figures 2-7 & 2-11) coincident with the province–wide cooling and moistening of the climate associated with the end of the Holocene mesothermic interval (Hebda 1995). However, this timing is slightly later than the regional wetting trend dated at 4700 ^{14}C yr BP (Gottesfeld et al. 1991).

One irregularity is the drying trend observed at Heckmann Pass, which is dated at 3800 ^{14}C yr BP (Hebda 1995) and runs counter to the moistening of the climate occurring in the rest of British Columbia at this time (Hebda 1995). This drying trend does, however, correlate with the transition from a moderate–rich fen to a poor fen (zones L-2 and L-3) at approximately 3890 ^{14}C yr BP in the continental peatland (Figure 2-12). A concurrent decrease in pH and increase in HAWT was also inferred at this transition despite the high decomposition and lack of bryophyte species in zone L-2 on which to base the reconstruction (Figures 2-6 & 2-7). Confidence that this transition was climate-driven, is limited, however, due to the large distance between Heckmann Pass and Adamson Bog, and the contrasting precipitation trends in the rest of British Columbia at that time. Until Holocene palaeoclimate is better understood in west – central British Columbia this possibility of localized drying of the climate influencing peatland development cannot be ruled out.

Correspondence with Other Allogenic Factors

Non-climatic allogenic factors may have influenced the peatland vegetation to a lesser degree with the transition between zones G-1 and G-2 interpolated at approximately 0 ^{14}C yr BP (AD 1950) corresponding to the construction of nearby Highway 16 from 1942-44 (Large 1996; Figure 2-10). Although both G-1 and G-2 are poor fen or bog zones the transition from G-2, a *Sphagnum* – dominated zone, to G-1, a zone dominated by the common forest floor species of *Pleurozium schreberi*, and *Ledum groenlandicum*, indicates a drying of the peatland surface that is reflected in the HAWT reconstruction (Figures 2-7 & 2-10). This change in regional drainage patterns associated with highway construction is a good example of how non-climatic, allogenic factors can influence peatland development. It is also possible that the increase in charcoal towards the surface zones of cores G and I reflects the increase in anthropogenic fire used by aboriginal people of the region (Gottesfeld et al. 1991), although it is more likely a function of the drier peatland surface having increased susceptibility to fire in general.

SUMMARY AND CONCLUSIONS

Peatland surface vegetation varied, primarily, along a climatic gradient in west – central British Columbia, as variations in the surface water pH were minimized through the selection of only ombrotrophic raised bogs. Specifically, surface vegetation assemblages of bogs from the interior and transitional climate zones were differentiated from those of coastal bogs. Peatlands of the transitional climate zone demonstrated a much greater vegetative similarity to the continental bog than to the coastal peatlands.

Higher levels of precipitation in the coastal region allowed the coastal peatlands to develop directly on mineral soil through paludification while two of the three more inland sites developed over lake peat by terrestrialization. The large volume of precipitation on the coast also influenced the peatland water chemistry, leading to a lower ion concentration and conditions unsuitable for growth of many rich fen bryophyte species (Gignac et al. 1991). In this manner, rich fen peat types were absent from the development sequences of both coastal sites.

The importance of the ombrotrophic – minerotrophic gradient in structuring peatland vegetation is reaffirmed by the ordination of all macrofossil samples, showing that peat types are more distinct, vegetationally, than peat cores. This illustrates that, while some peat types are unique to particular climatic zones, peat types common to all zones are vegetationally more similar within the peat type than to other peat types from the same climate zone. As with the surface vegetation, peatlands in the transitional region showed more affinity to the continental peatland than the coastal peatlands with regards to palaeo-vegetation communities.

Allogenic climatic factors are known to be important in influencing both peatland type (Damman 1977; Glaser and Janssens 1986; Vitt et al. 1994) and abundance on the landscape (Halsey et al. 1997). Autogenic processes are known to be of fundamental importance in peatland development (Kuhry et al. 1993; Vitt 1994; Turunen and Turunen 2003). Results of this study show that, at an individual peatland scale, climate change appears to have controlled the timing of peat initiation but was of secondary importance to autogenic processes once peat accumulation was underway. The warming and moistening of the climate at approximately 4000 ^{14}C yr BP correlates surprisingly well with the distinctive transition to the often *Sphagnum* – dominated poor fen or bog zones at the continental and transitional sites. This appears to be incidental, however, as the transition from high pH, low HAWT rich fens to low pH, high HAWT poor fens or bogs is opposite to what would be expected from a wetter climate. In fact, when this transition is closely examined, both transitional zone peatlands show a re-moistening of the peatland surface at this time, causing an approximately 1000 ^{14}C year delay in the autogenic successional trends towards ombrotrophy. Lack of palaeoclimate records in the central interior of the province introduces uncertainty into the regional climate trend and localized drying of the climate cannot be ruled out, at this time, as a possible influence on the development of the most continental peatland. Despite the predominant trend of autogenic factors influencing peatland development, there are clear indications that allogenic climate factors can also be strongly influential and counteract the autogenic influences. In this manner, allogenic factors may cause peatland development to deviate from the more classic autogenic successional trend from minerotrophy towards ombrotrophy.

Based on the five peatlands studied, there were substantial differences in the development pattern across climatic zones that may suggest other differences in terms of peatland function. These differences, from the more widely studied continental peatlands, should be examined further if carbon accumulation and responses to climate change are to be accurately predicted in peatlands of north coastal British Columbia.

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Table 2-1: Sample characteristics and results of accelerator mass spectrometry (AMS) ^{14}C dating for peat cores from Butze Rapids (A & B), Green River (C, D, & E), Highway (F & G), Powerline (H & I), and Adamson (J, K, & L) bogs. Calibrated ages refer to the probability weighted mean age as calculated from CALIB (Stuiver and Reimer 1993) rev. 5.0 using the standard calibration data set IntCal04 (Reimer et al. 2004). Laboratory designation: AA = University of Arizona; TO = Isotrace Laboratory, University of Toronto.

Lab ID	Core	Depth (cm)	Conventional ^{14}C date (yr BP)	Calibrated age (cal. yr BP)	Maximum calibrated age range (2σ)	Dated Material
AA47691	A	113	765 ± 65	710	561 - 898	*Sphagnum, Racomitrium*
AA47692	A	193	1776 ± 43	1700	1569 - 1819	*Sphagnum*
TO-9266	A	316.5	7610 ± 90	8410	8205 - 8588	wood, *Sphagnum*, herbaceous remains
TO-9267	B	269.5	5440 ± 70	6220	6004 - 6396	gymnosperm wood
AA47693	C	92	2730 ± 45	2830	2754 - 2925	*Sphagnum*
AA47694	C	176	3042 ± 53	3250	3078 - 3370	*Sphagnum, Pinus* needles
AA47695	C	260	5955 ± 53	6790	6666 - 6930	*Sphagnum*, herbaceous rhizome, woody rhizome
TO-9268	C	344.5	7470 ± 110	8270	8024 - 8452	wood, herbaceous remains
TO-9269	D	303.5	7870 ± 100	8730	8457 - 8995	*wood, Sphagnum*
TO-9270	E	305.5	4160 ± 60	4690	4529 - 4837	herbaceous rhizome
TO-9271	F	285.5	8470 ± 80	9460	9278 - 9559	limnic and detrital peat
AA47697	G	195.5	6374 ± 47	7320	7178 - 7422	*Sphagnum, Tomentypnum*
TO-9272	G	285	8590 ± 70	9580	9466 - 9736	limnic and detrital peat
TO-9273	H	376.5	8530 ± 80	9520	9322 - 9692	angiosperm wood
AA47698	I	215.5	4135 ± 54	4670	4523 - 4830	Cyperaceae seeds, dicot leaf fragments, *Sphagnum*
AA47699	I	296	5684 ± 45	6470	6324 - 6631	*Picea mariana* needles, Cyperaceae seeds
TO-9274	I	416.5	8830 ± 80	9910	9627 - 10181	wood, Cyperaceae seeds, *Sphagnum*
TO-9275	J	252.5	6730 ± 60	7590	7490 - 7679	limnic and detrital peat
TO-9276	K	257.5	7930 ± 130	8790	8447 - 9121	limnic and detrital peat
AA47700	L	168.5	4726 ± 55	5460	5322 - 5586	Cyperaceae seeds, Betula seeds, dicot leaf fragments
TO-9277	L	279.5	7770 ± 70	8550	8405 - 8749	limnic and detrital peat

Table 2-2: Significant Pearson correlations (r) of distance from the coast with percent cover of surface vegetation species averaged within each peatland.

Abreviation	Species	n	r
Bryophytes			
Cephcon	*Cephalozia connivens*	5	-.957(*)
Spharub	*Sphagnum rubellum*	5	-.979(**)
Lichens			
Cladcri	*Cladonia crispata*	5	-.879(*)
Cladfur	*Cladonia furcata*	5	-.970(**)
Herbs			
Careplu	*Carex pluriflora*	5	-.941(*)
Gentdou	*Gentiana douglasiana*	5	-.985(**)
Triaglu	*Triantha glutinosa*	5	-.979(**)
Trieeur	*Trientalis europaea* ssp. *arctica*	5	-.879(*)
Shrubs			
Andrpol	*Andromeda polifolia*	5	-.970(**)
Junicom	*Juniperus communis*	5	-.942(*)
Kalmmic	*Kalmia microphylla*	5	-.988(**)
Trees			
Thujpli	*Thuja plicata*	5	-.985(**)

* correlation is significant at the $\alpha = 0.05$ level

** correlation is significant at the $\alpha = 0.01$ level

Table 2-3: Classification of core zones including species indicative of each zone as determined by the method of Dufrêne and Legendre (1997). Within one core, each species was only tested for significance in the zone in which it had its maximum indicator value. If a species had an indicator value ≥ 25 in a second zone it is also listed in that zone, without a p-value.

Zone	Indicator Taxa	Indicator Value	p	Peat Type
A-1	*Sphagnum austinii*	92	0.0010	oceanic fen / bog
A-2	section Acutifolia *Sphagnum*	57	0.0030	poor fen
	herbaceous remains	37		
A-3	debris	94	0.0010	herbaceous fen
	Pteridophytae roots	69	0.0020	
	herbaceous remains	57	0.0060	
	charcoal	40	0.0370	
	Hylocomium splendens	31	0.0480	
	wood	31	0.0480	
C-1*				oceanic fen /bog
C-2	herbaceous remains	32	0.0300	herbaceous fen
C-3	*Racomitrium lanuginosum*	99	0.0010	oceanic fen / bog
C-4**				oceanic poor fen
C-5	*Sphagnum papillosum*	90	0.0120	oceanic poor fen
C-6	section Cuspidata *Sphagnum*	60	0.0220	poor fen
C-7	Pteridophytae roots	62	0.0330	poor fen
	section Acutifolia *Sphagnum*	50	0.0260	
C-8	debris	39	0.0010	poor fen
	Pteridophytae roots	28		
G-1	*Ledum groenlandicum*	100	0.0050	poor fen /bog
	Pleurozium schreberi	100	0.0030	
G-2	*Sphagnum magellanicum*	99	0.0010	poor fen / bog
G-3	herbaceous remains	30		herbaceous fen
	debris	27		
G-4	*Sphagnum teres*	99	0.0030	moderate rich fen
	Tomentypnum nitens	67	0.0030	
G-5	*Bryum* sp.	67	0.0130	extreme rich fen
	Meesia triquetra	63	0.0280	
	Betula *sp.*	62	0.0100	
	Campylium stellatum	61	0.0150	
	Carex *cf.* pluriflora *roots*	53	0.0300	
	Calliergon trifarium	50	0.0420	
	herbaceous remains	50	0.0010	
G-6	*Scorpidium scorpioides*	90	0.0010	extreme rich fen
	Calliergon trifarium	34		
G-7	*Chara* sp.	72	0.0050	lake / shallow water
	shells	52	0.0160	
	debris	46	0.0010	
G-8	mineral soil	67	0.0130	mineral soil
	marl	57	0.0230	
I-1	*Carex* cf. *pluriflora* roots	49	0.0420	bog
	Sphagnum fuscum / rubellum	36		
	woody root	26		
I-2	woody root	47	0.0260	herbaceous fen
	herbaceous remains	31		
I-3	*Sphagnum fuscum / rubellum*	54	0.0010	bog
I-4	*Scorpidium scorpioides*	62	0.0230	extreme rich fen
	wood	56	0.0370	

	Calliergon giganteum	52	0.0400	
	herbaceous remains	47	0.0050	
I-5	mineral soil	100	0.0010	mineral soil
	Pteridophytae roots	63	0.0120	
L-1	*Sphagnum angustifolium*	75	0.0010	poor fen / bog
	Pleurozium schreberi	75	0.0010	
	Picea mariana	58	0.0030	
	Ptilium crista-castrensis	50	0.0120	
	woody root	37		
L-2	debris	55	0.0010	poor fen
	woody root	46	0.0150	
L-3	*Drepanocladus aduncus*	67	0.0010	moderate rich fen
	Pteridophytae root	43	0.0330	
	herbaceous remains	34		
L-4	herbaceous remains	50	0.0020	herbaceous fen
L-5	shells	100	0.0010	lake / shallow water
	marl	73	0.0010	
L-6*				mineral soil

* zones contained only one sample so Indicator Species analysis could not be run

** no significant indicator species in the zone

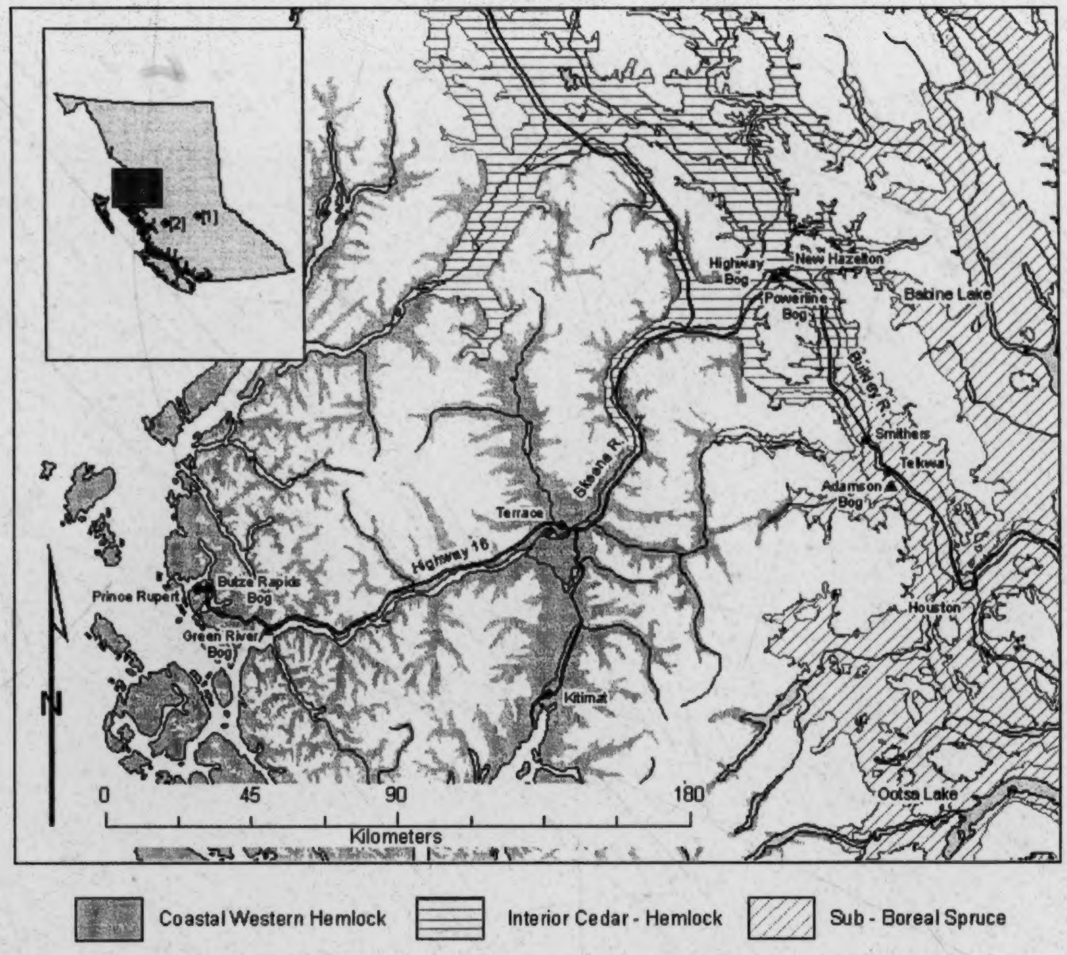

[2]
[1]
Highway Bog
New Hazelton
Powerline Bog
Babine Lake
Bulkley R.
Smithers
Telkwa
Adamson Bog
Skeena R.
Terrace
Highway 16
Butze Rapids Bog
Prince Rupert
Green River Bog
Houston
Kitimat
Ootsa Lake
N
0
45
90
180
Kilometers
Coastal Western Hemlock
Interior Cedar - Hemlock
Sub - Boreal Spruce

Figure 2-1: Map showing study site locations ▲ and relevant Biogeoclimatic Zones in west – central British Columbia. Inset map also shows the approximate location ● of two published palaeoclimate records mentioned in the discussion, where [1] represents Pantage Lake, and [2] Heckmann Pass.

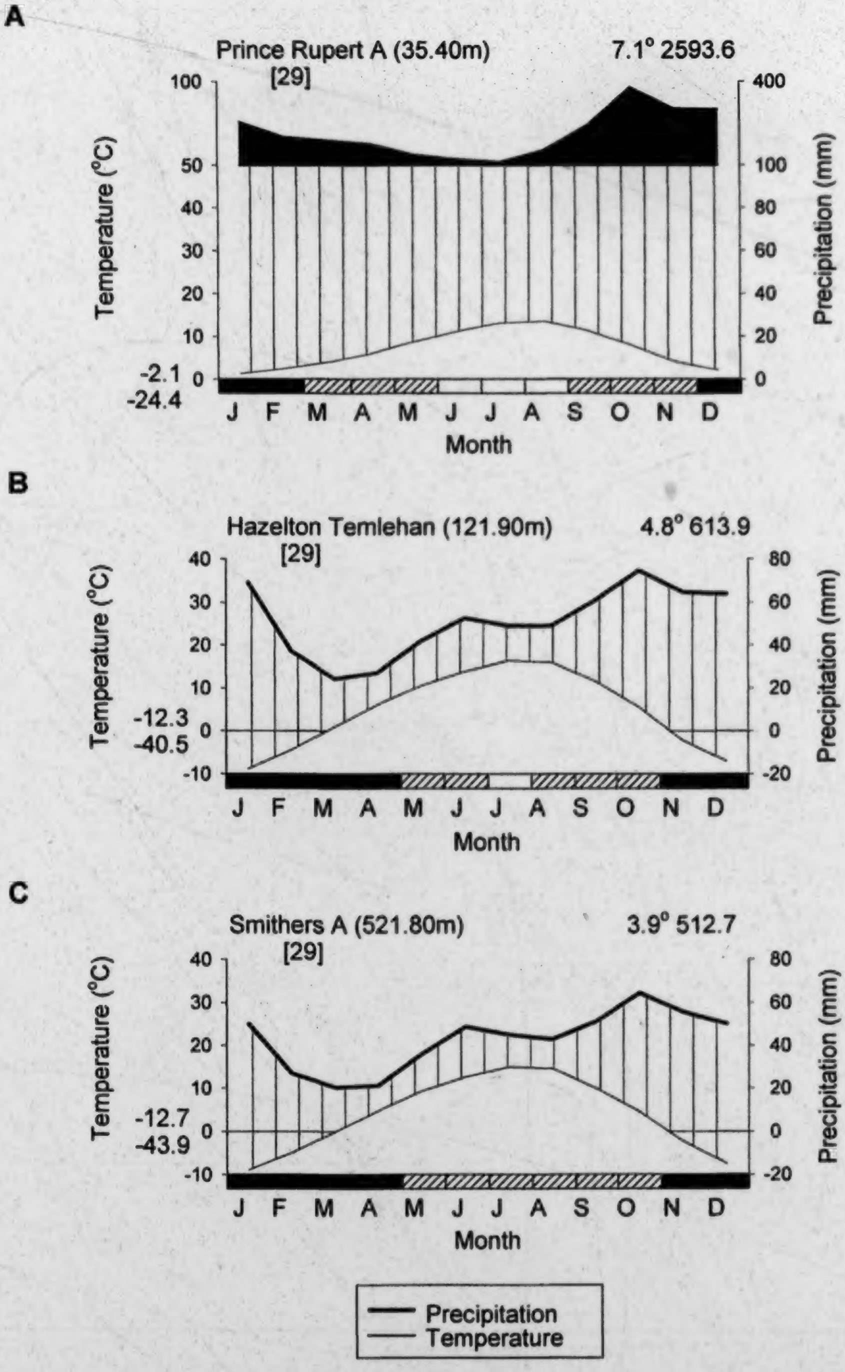


Figure 2-2 A to C: Climate diagrams for stations in the A) CWH B) ICH and C) SBS Biogeoclimatic zones. Data is derived from the Canadian Climate Normals 1971-2000 (Environment Canada 2002) and interpretation of the diagrams follows Walter (1963).

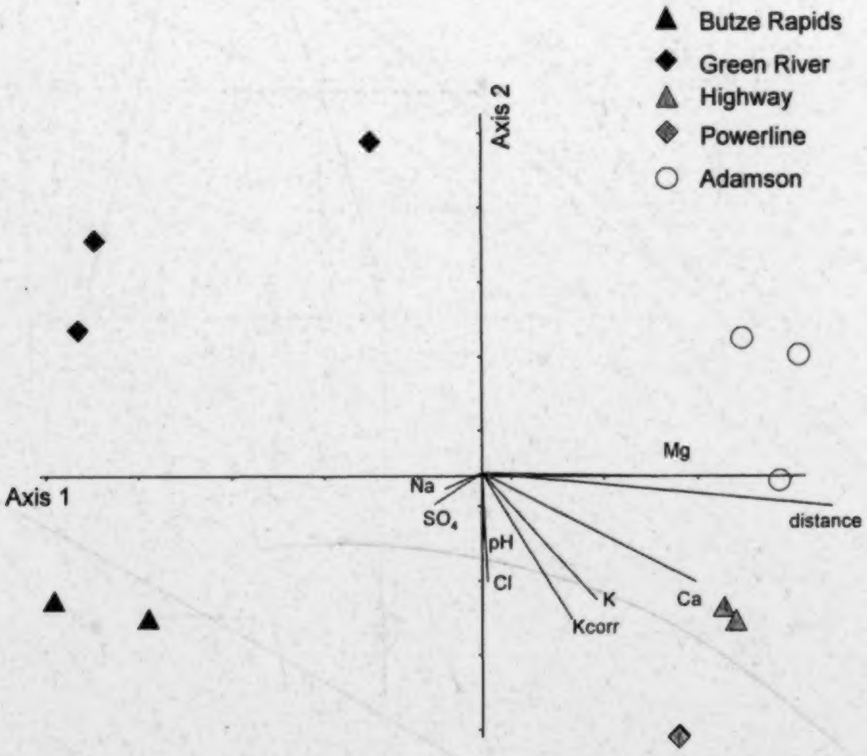


Figure 2-3: NMDS ordination of surface vegetation data showing location of sites on the ordination. Environmental variables are depicted as vectors overlain on the ordination through correlations with the axes, such that the angle and length of the vector represents the direction and strength of the relationship. Vector labels represent abbreviations of relative distance from the coast (distance), and the corrected conductivity (kcorr), pH, and concentrations of various ions (Mg, Ca, K, Cl, SO4, and Na) in surface water samples from each vegetation plot. White symbols = continental sites, grey symbols = transitional sites, and black symbols = coastal sites.

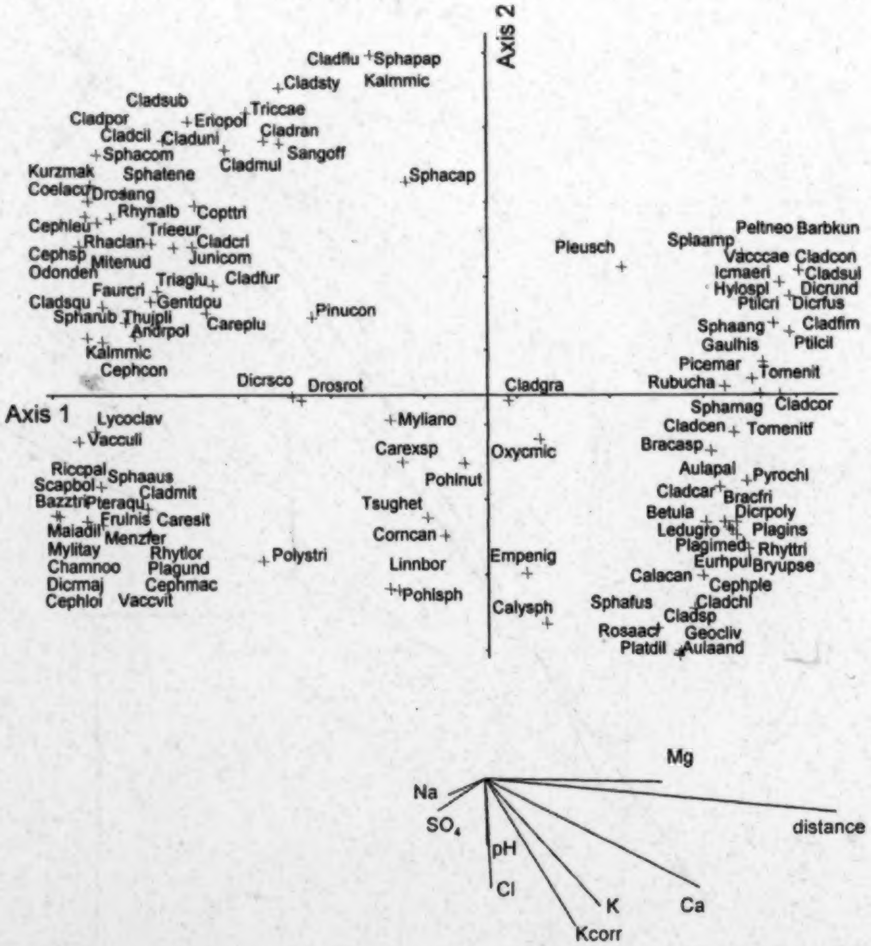


Figure 2-4: NMDS ordination of surface vegetation data showing location of species on the ordination. Environmental variables are depicted as vectors overlain on the ordination through correlations with the axes, such that the angle and length of the vector represents the direction and strength of the relationship. Vector labels represent abbreviations of relative distance from the coast (distance), and the corrected conductivity (kcorr), pH, and concentrations of various ions (Mg, Ca, K, Cl, SO4, and Na) in surface water samples from each vegetation plot. Species labels consist of the first four letters of th genus name and the first three letters of the specific epithet.

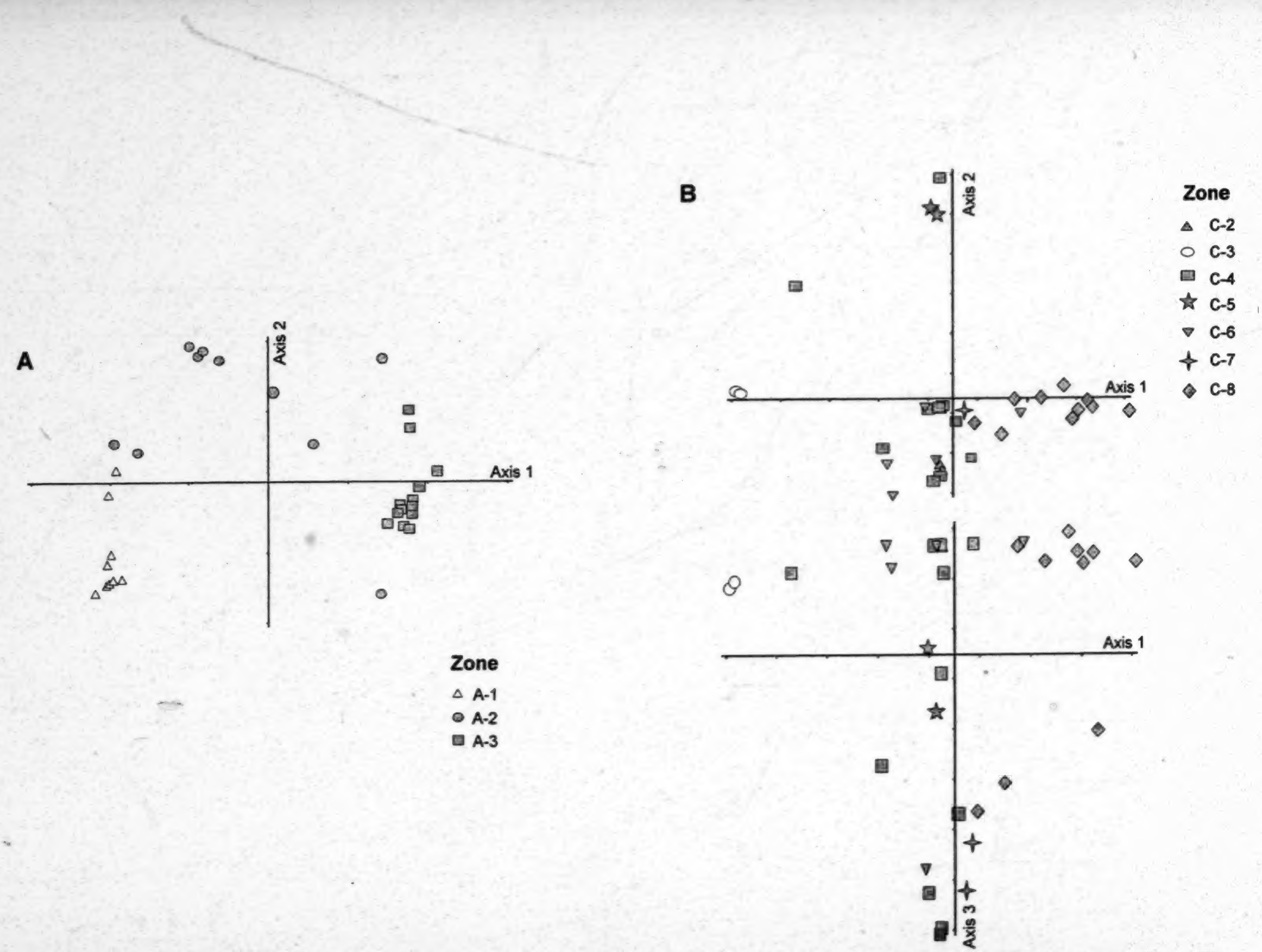


Figure 2-5 A to E: NMDS ordinations of core zones using the macrofossil abundance data from Butze Rapids (A), Green River (B), Highway (C), Powerline (D), and Adamson (E) bogs. White symbols = bog/poor fen peat, light grey symbols = poor fen or herbaceous peat, dark grey symbols = moderate rich or extreme rich fen peat, and black symbols = lake or shallow open water peat.

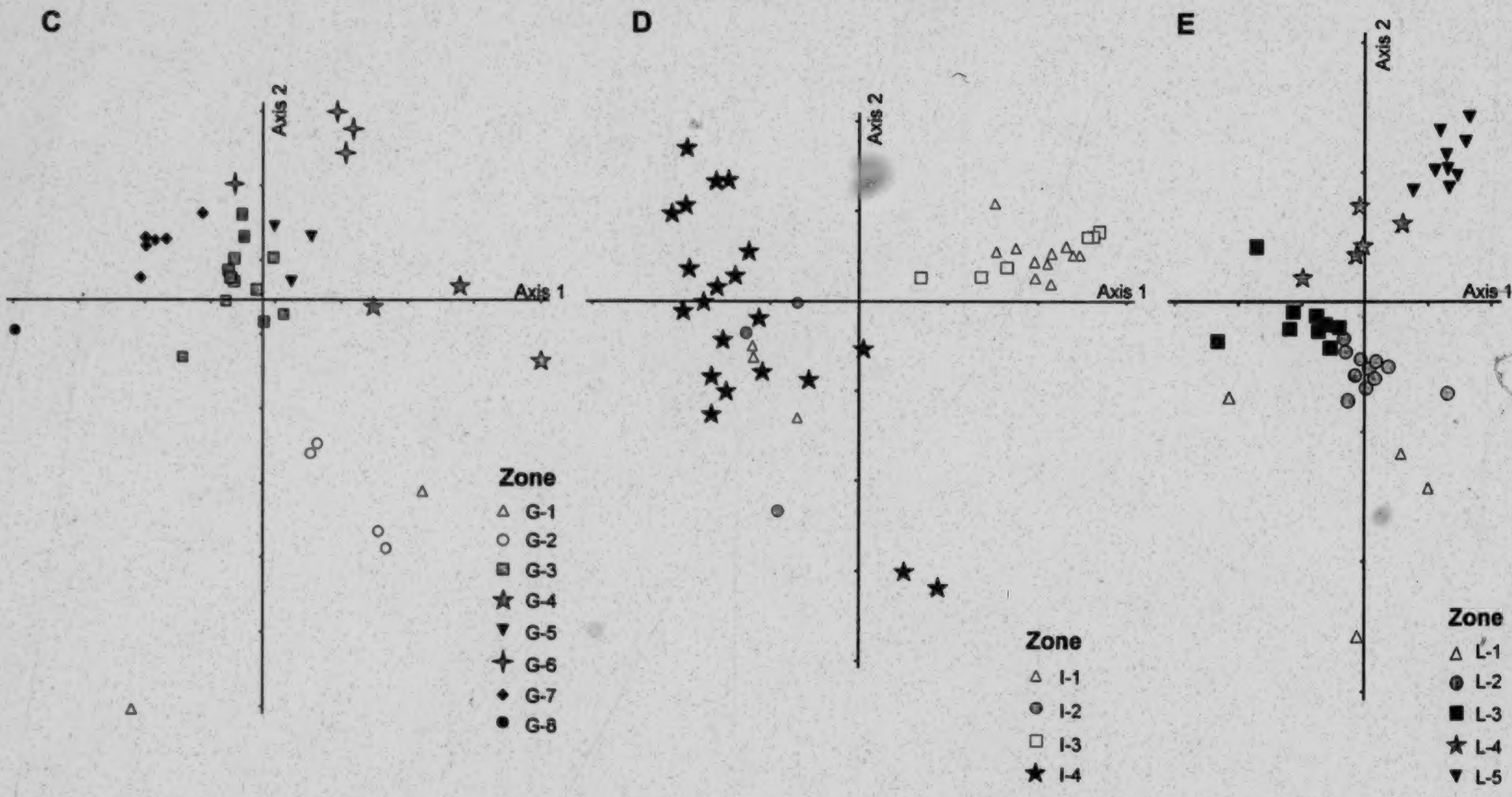


Figure 2-5 continued

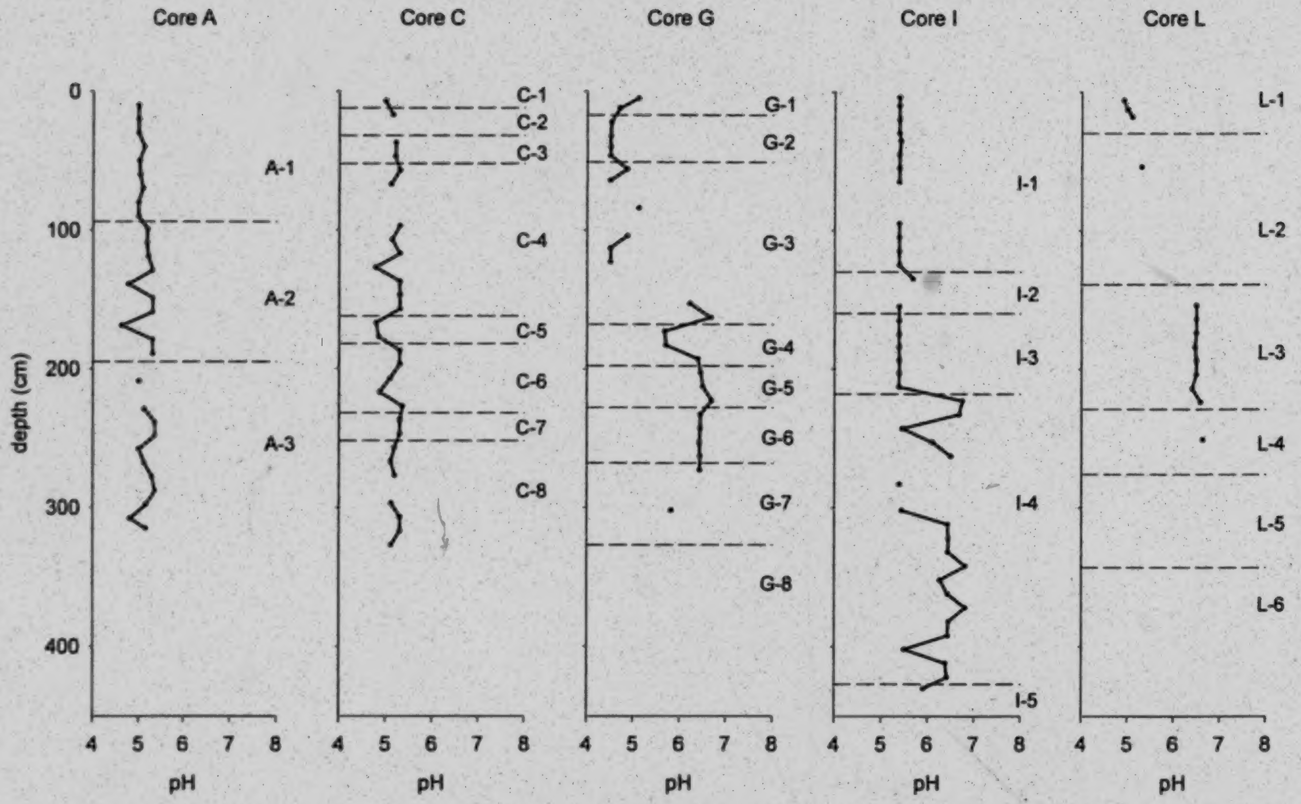


Figure 2-6: Past changes in pH for Butze Rapids (Core A), Green River (Core C), Highway (Core G), Powerline (Core I), and Adamson (Core L) bogs as reconstructed from the bryophyte macrofossil record. Gaps in reconstructed profiles represent regions where a lack of bryophyte species in the macrofossil samples prevented reconstruction of the pH.

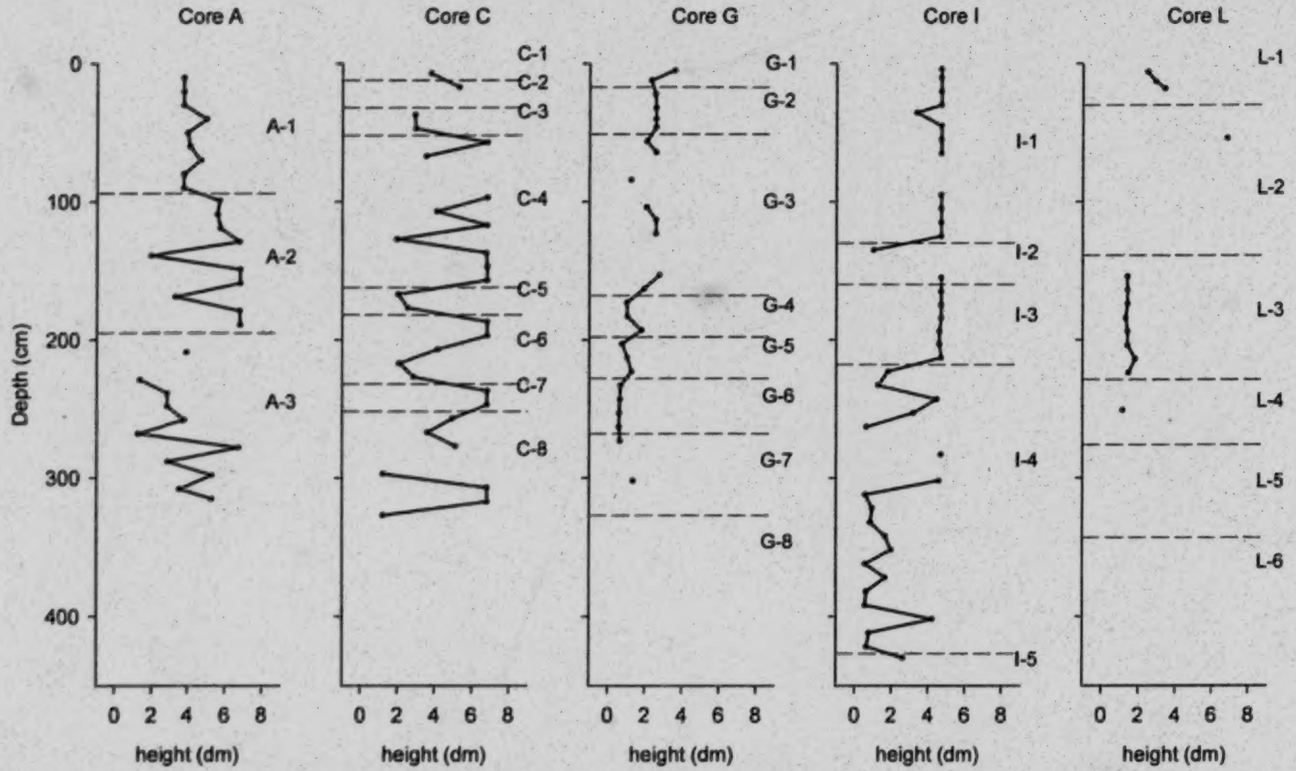


Figure 2-7: Past changes in height of the peatland surface above water table for Butze Rapids (Core A), Green River (Core C), Highway (Core G), Powerline (Core I), and Adamson (Core L) bogs as reconstructed from the bryophyte macrofossil record. Gaps in reconstructed profiles represent regions where a lack of bryophyte species in the macrofossil samples prevented reconstruction of the height above water table (HAWT).

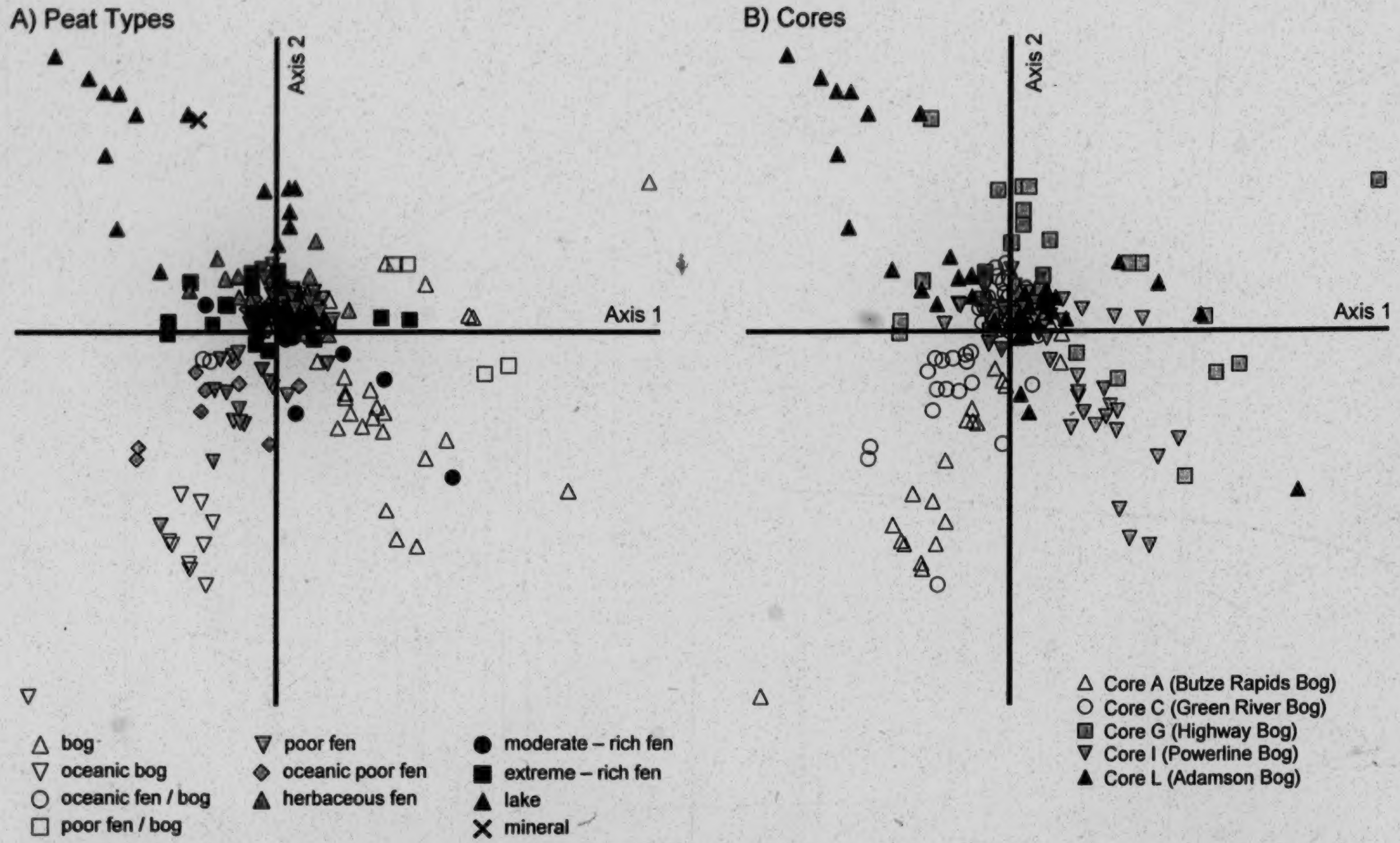


Figure 2-8 A, B: Non-metric multidimensional scaling (NMDS) ordination of macrofossil data from all cores showing distribution of (A) peat types and (B) the five cores. In (B) white symbols = coastal sites, grey symbols = transitional sites, and black symbols = continental sites.

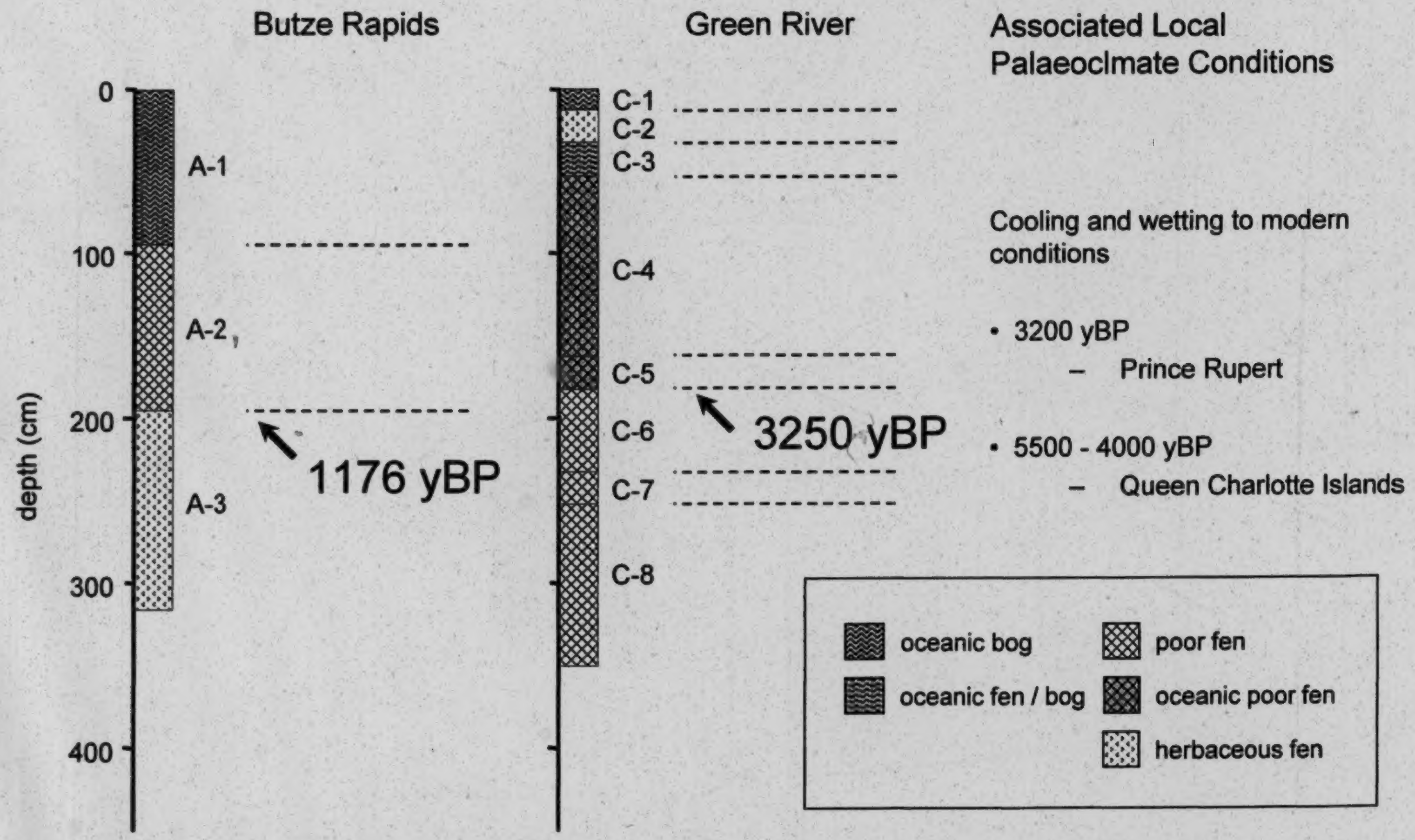


Figure 2-9: Relationships between the timing of important peat type transitions in coastal zone bogs, compared to local palaeoclimate trends reviewed by Hebda (1995). Dates of zone boundaries are linearly interpolated from within-core dates presented in Table 2-1.

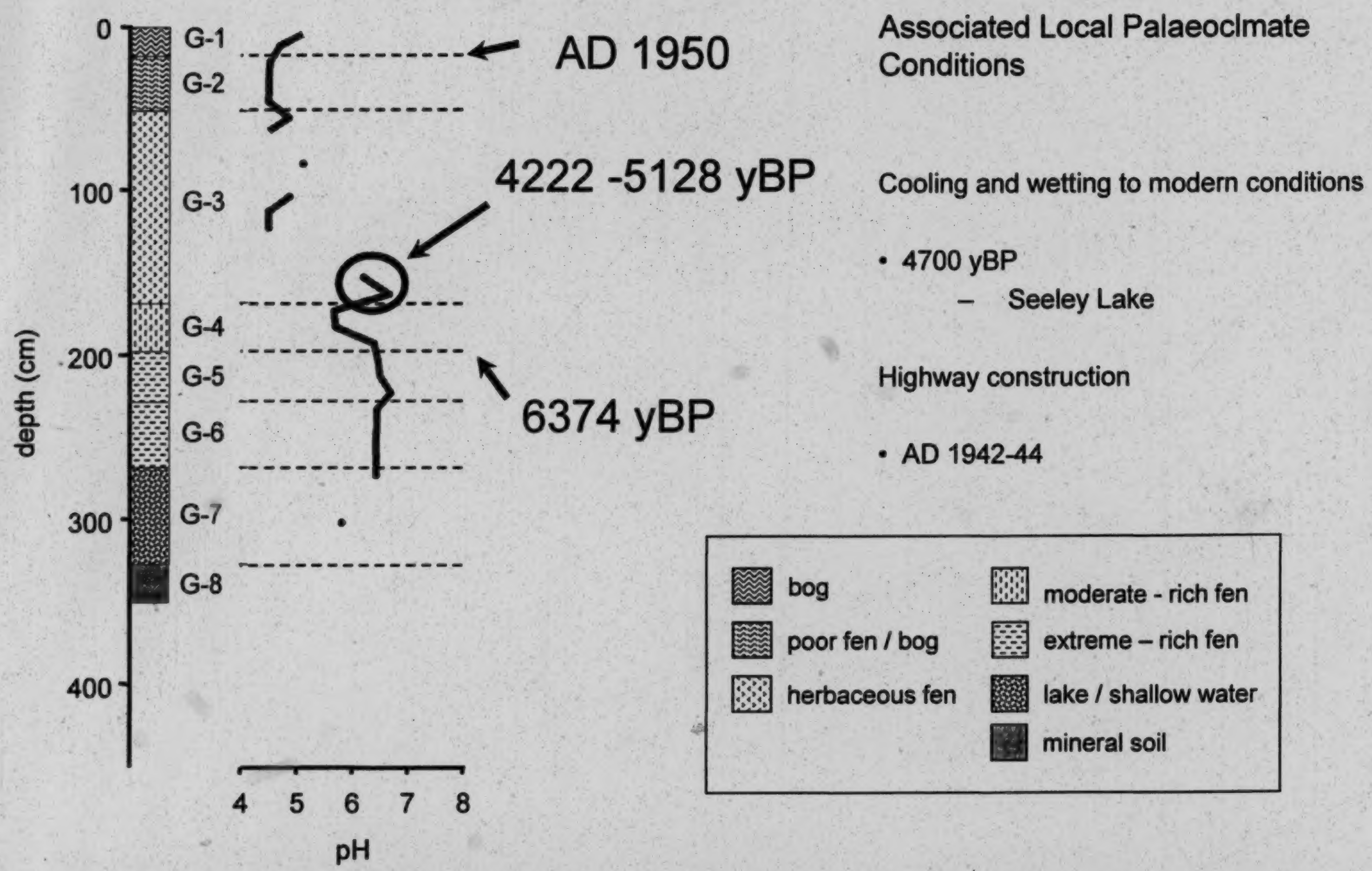


Figure 2-10: Relationships between the timing of important vegetative, and pH, changes in Highway Bog (located in the transitional climate zone), compared to local palaeoclimate trends (Gottesfeld et al. 1991) and recent highway construction (Large 1996). Dates of zone boundaries are linearly interpolated from within-core dates presented in Table 2-1.

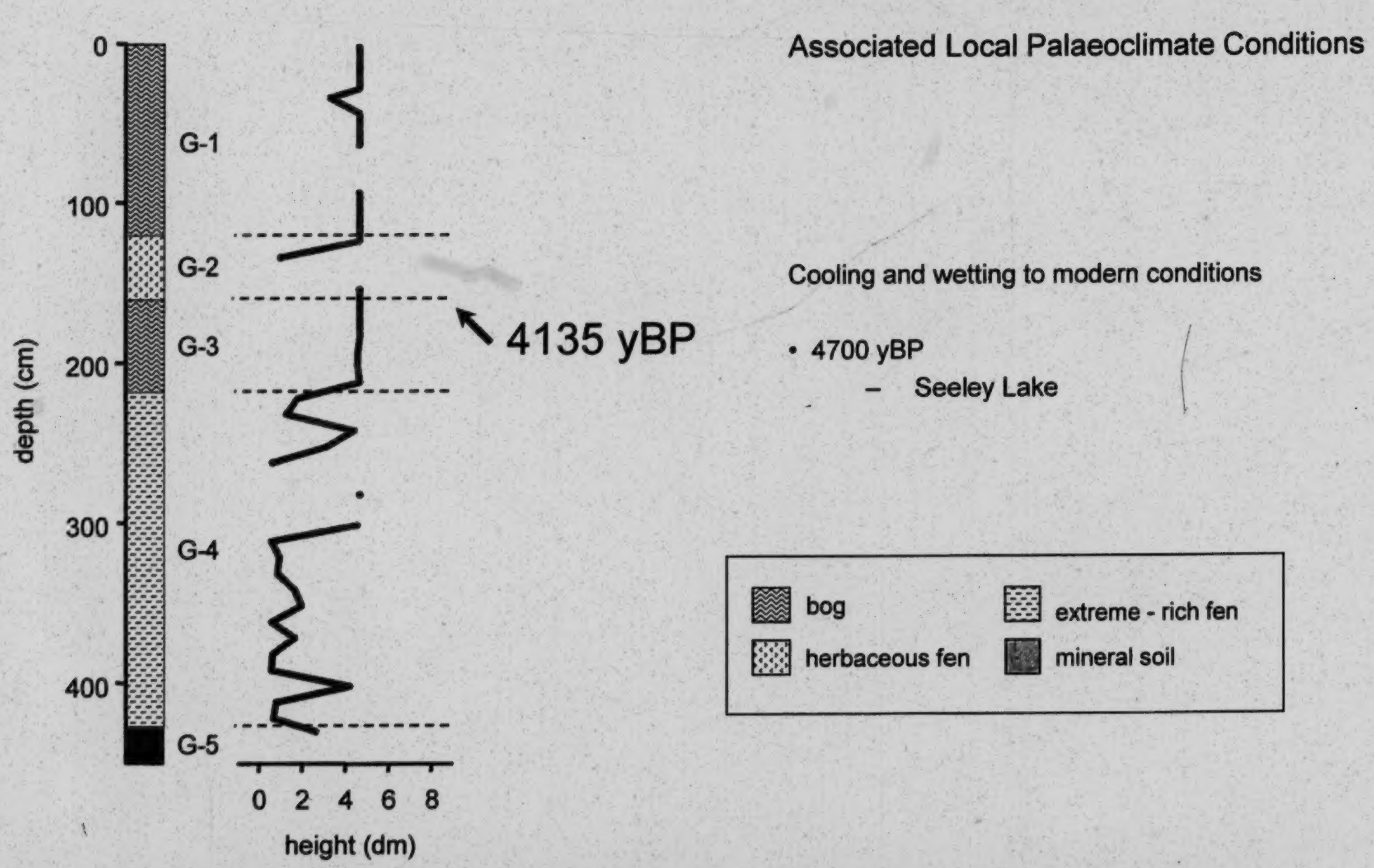
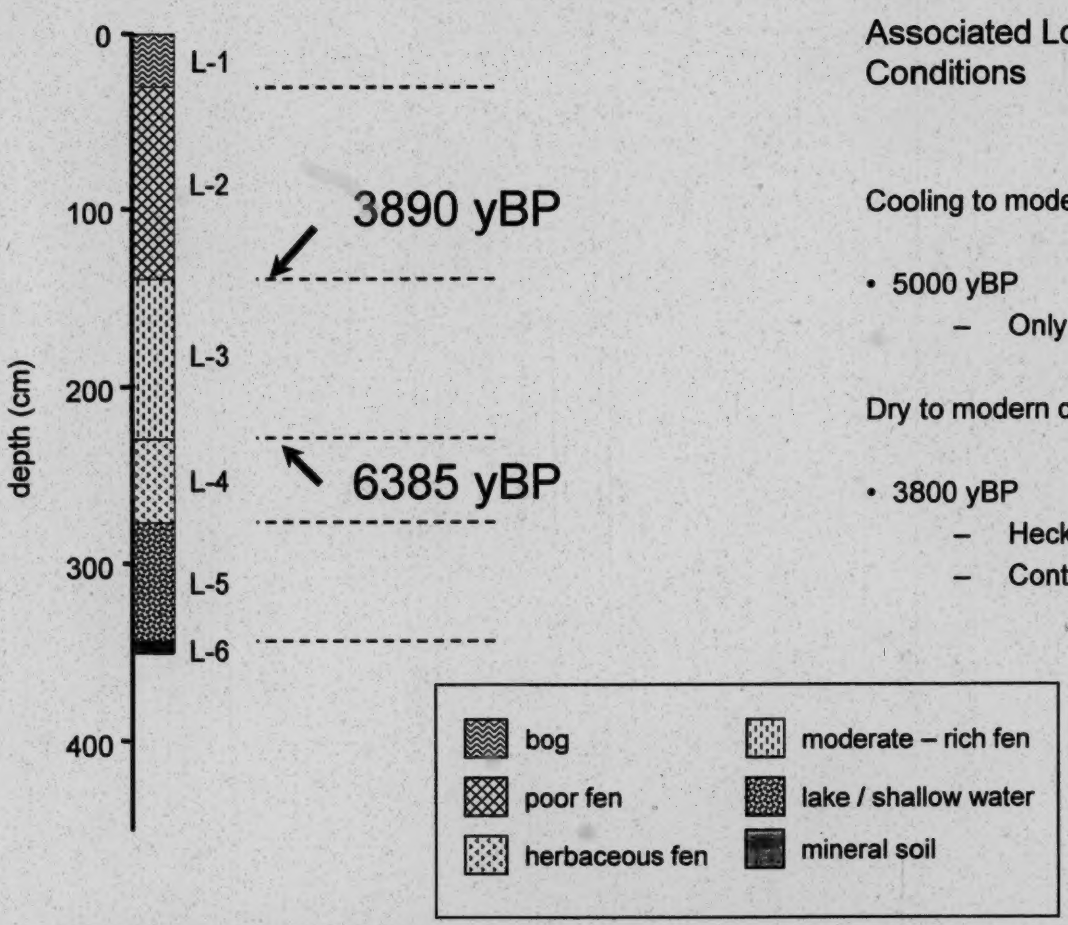


Figure 2-11: Relationships between the timing of important peat type, and height-above-water-table, changes in Powerline Bog (located in the transitional climate zone), compared to local palaeoclimate trends (Gottesfeld et al. 1991). Dates of zone boundaries are linearly interpolated from within-core dates presented in Table 2-1.


depth (cm)
0
100
200
300
400
L-1
L-2
L-3
L-4
L-5
L-6
3890 yBP
6385 yBP
bog
poor fen
herbaceous fen
moderate – rich fen
lake / shallow water
mineral soil

Associated Local Palaeoclimate Conditions

Cooling to modern conditions

- 5000 yBP
  - Only record in SBS (Pantage Lake)

Dry to modern conditions

- 3800 yBP
  - Heckmann Pass (subalpine)
  - Contradicts other BC records

Figure 2-12: Relationships between the timing of important peat type changes in Adamson Bog (located in the interior climate zone), compared to local palaeoclimate trends from Pantage Lake and Heckmann Pass (Hebda 1995; Figure 2-1). Dates of zone boundaries are linearly interpolated from within-core dates presented in Table 2-1.

CHAPTER 3

Carbon accumulation in peatlands along a climatic gradient in west - central British Columbia, Canada

INTRODUCTION

Peatlands are waterlogged terrestrial ecosystems where, due to anaerobic conditions, rates of organic matter production exceed rates of decomposition resulting in accumulation of organic matter on the landscape. Once this organic matter has reached a depth of 40 cm it is designated as a peatland under the Canadian System of Wetland Classification (Zoltai 1988). Because peat accumulates in situ from surface vegetation, peatlands provide a stratigraphic record of past vegetation in the form of partially decomposed plant remains (macrofossils) preserved as part of the peat (Vitt and Kuhry 1992). Identification of these macrofossils allows for a reconstruction of prior peatland communities which can then be classified into general peatland types based on current species assemblages (e.g. Nicholson and Vitt 1990; Chapter 2).

The basis of peatland classification is fundamentally hydrological with ombrotrophic systems (bogs) influenced only by precipitation derived water, and minerotrophic systems (fens) influenced to varying degrees by water that has been in contact with mineral soil (Vitt 1994). A gradient of poor fens through to extreme rich fens results from an increasing influence of minerotrophic groundwater that is reflected in an increasing number of rich fen indicator plant species (DuRietz 1949). Vegetationally and chemically the main distinction among peatland types lies between the alkaline, brown moss (mostly Amblystegiaceae) dominated rich fens and the acidic, *Sphagnum* – dominated bogs and poor fens (Vitt 1994). The gradient from fen to bog represents a common autogenic successional sequence (Nicholson and Vitt 1990; Janssens et al. 1992; Kuhry et al. 1993) as peat growth raises the surface vegetation farther from the influence of the minerotrophic groundwater. The relationship of *Sphagnum* species to peatland development is also important because of their ability to further acidify the system through the exchange of cations for hydrogen ions (Clymo 1963, 1987; Craigie and Maass 1966; Gorham et al. 1987). Once *Sphagnum* becomes established in a peatland, there is a period of rapid transition in surface water chemistry from pHs above 6.0 to pHs less than 5.5 (Gorham et al. 1984; Vitt and Kuhry 1992) and, commonly, peatlands with ombrotrophic surface vegetation contain deeper peat horizons that were formed under more minerotrophic conditions.

In addition to autogenic successional changes, climate is an important factor influencing the peatland type and surface vegetation communities (Damman 1977; Ruuhijärvi 1983; Glaser and Janssens 1986; Glaser 1992) as well as the abundance of peatlands on the landscape (Kuhry and Zoltai 1994; Vitt 1994; Halsey et al. 1997; Halsey et al. 1998), and rate of peat accumulation (Botch et al. 1995; Turunen et al. 2002). In north coastal British Columbia, high levels of precipitation result in a near constant supply of water encouraging the development of peatlands not only in basins but across the landscape, covering from 51 to 75% of the terrain (Banner et al. 1986; Banner et al. 1988). In contrast, peatlands found in the mid Boreal climate of interior British Columbia, are influenced by much lower levels of precipitation and are thus restricted to basins and shallow slopes, occupying only less than 5% of the terrain (Zoltai et al. 1988). Peatland bryophyte species are also seen to vary along the gradient from coastal to continental climates in western Canada (Gignac and Vitt 1990; Gignac et al. 1991b) as do the vascular plant communities (compare Zoltai et al. 1988 and Vitt et al. 1990).

Because peat is composed of partially decayed organic matter, peatland growth represents a transfer of atmospheric carbon (C) to the soil. Canada is thought to possess the second highest peatland area of any country in the world (Gorham 1991) and with the retreat of ice sheets following the Wisconsin Glaciation in the late Pleistocene and early Holocene (Clague 1984; Dyke and Prest 1987), Canadian peatlands have been functioning as a net C sink (Vitt et al. 2000; Gajewski et al. 2001). Currently, peatlands represent approximately one third of the global soil C stocks (Gorham 1991), which are equivalent to 60% of the CO_2 – C currently stored in the atmosphere (Nilsson et al. 2001). Recent interest in the predominantly C – based greenhouse gases and their role in global warming and has increased scientific focus on worldwide C budgets. In turn, this has resulted in an increased interest in understanding the processes involved in peatland C accumulation.

In North America, Gorham et al. (2003) report long term apparent rates of C, and peat, accumulation to be inversely correlated with mean annual precipitation, with coastal peatlands generally supporting lower accumulation rates than peatlands found in the drier continental climates. Although only one of the sites reported by Gorham et al. (2003) was from the Pacific Coast, the only other study of long term peat accumulation from the West Coast of North America supports this trend, recording extraordinarily low peat and C accumulation rates (Turunen and Turunen 2003), below any of those identified by Gorham et al. (2003).

Long term peat accumulation is often described in terms of a conceptually simple model introduced by Clymo (1984) indicating declining rates of peat accumulation over time. Although the Clymo model was developed (and applied with remarkable success) for oceanic bogs of western Europe it has been less successfully applied in fens and continental peatlands of both North America and Europe (Clymo et al. 1998; Yu et al. 2000; Turunen et al. 2001). Once again, most North American studies of peat accumulation have been conducted in continental regions or along the Atlantic coast. The few peat accumulation studies along the Pacific Coast of North America indicate conflicting results with peatlands showing both increasing in decreasing rates of peat accumulation over time (Gorham et al. 2003; Turunen and Turunen 2003).

While many peat accumulation studies look primarily at trends of total C accumulation throughout a peat core, variations of C concentration within the peat of a single core are seldom considered. Peat bulk density (BD) is known to relate directly to the C concentration of peat (Vitt et al. 2000) and a profile of BD within a core is considered necessary in the modelling of peat and C accumulation (Clymo 1984; Clymo et al. 1998). It has long been observed that the depth of an individual sample within a peat core may influence the BD (and thus the peat C density) through processes of decomposition and compaction (Clymo 1984) and that peat BD is influenced by generalized peat types based on macrofossil composition (Nicholson 1989; Beilman 2001; Bauer et al. 2005). Because autogenic successional patterns often result in fen peat types occurring deeper in the peat cores than bog peat types, BD trends associated with depth are easily confused with those due to the material type forming the peat and vice versa. In order to understand variations of C density within a peat core, one must first separate the influences of depth, degree of decomposition, and material type on the peat BD.

With limited long term apparent rates of C accumulation (LORCAs) available from the West Coast of North America and a need for more studies of C accumulation trends along a precipitation gradient , particularly in western North America (Gorham et al. 2003), this study represents a preliminary inquiry into peatland C accumulation along a gradient from coastal to continental climates in west – central British Columbia. Specifically, the questions I will address are:

1. What are the LORCAs in west-central British Columbia?
2. What are the long term apparent rates of peat accumulation in west-central British Columbia?
3. Do LORCAs differ between climatic regions?
4. Do trends in cumulative peat C mass support the Clymo (1984) model of declining accumulation rates over time?
5. Does depth from the peat surface cause an increase in BD, and thus increase the C concentration of the peat?
6. Do peatland development patterns influence the BD, and thus the C concentration of the peat?
7. Does the type of peat, specifically the vegetative composition, influence the peat BD, and thus the C concentration of the peat?

APPROACH AND METHODOLOGICAL BACKGROUND

In order to clarify the Methods section a brief discussion follows, outlining the basic approach used to answer the seven objective questions in terms of data used and a brief discussion of the more complex methodologies.

Each of the seven questions involve the use of ashless bulk density (BD_a) profiles from peat cores of five bogs distributed along a gradient from coastal to continental climate zones in west – central British Columbia. The three questions involving C accumulation (questions one, three, and four) also rely on the literature to convert dry peat mass (as derived from BD_a) to peat C mass. Temporal control is necessary when rates of peat and C accumulation are involved, as in the first four questions, and requires the use of calibrated basal ^{14}C dates with question four additionally using calibrated mid-core ^{14}C dates.

For the discussion of peatland developmental patterns and the vegetative composition of peat, both data and interpretation resulting from the detailed macrofossil analysis presented in Chapter 2 are used. Question six, in particular, involves a discussion of peatland development substantiated by zonation of the peat cores, and the interpretation of these zones presented in Chapter 2. In answer to how the peat type and vegetative composition, influence the peat BD (question seven) two strategies are employed. Firstly, the BD_a is compared among peat types identified through the analysis presented in Chapter 2. However, the use of generalized peat types obscures possible variations in BD_a due to specific macrofossil taxa and because general peatland successional sequences cause some peat types to be found deeper in the peat cores, trends in BD_a among peat types are difficult to separate from trends in BD_a with depth. In order to address these two concerns, the second strategy employed to answer question seven uses response surfaces to plot the abundance of specific macrofossil types simultaneously against both BD_a and depth in the peat core for three climate regions. Response surfaces allow for a visual representation of species abundances relative to two variables, while allowing for interaction between the variables and assuming neither a Gaussian model, nor a symmetric response about the mean for either variable (Gignac et al. 1991a). Commonly used in ecological studies to describe species niches along ecological gradients, response surfaces have been used in a peatland context to depict niches of bryophyte and Cyperaceae species along gradients of pH and height above the water table (Gignac et al. 1991b; Gignac et al. 2004).

STUDY AREA

The climatic gradient studied in west – central British Columbia encompasses three Biogeoclimatic Zones (BGCZs) reflecting the regions of coastal climate, continental climate, and transitional climate that result from an intermingling of the continental air masses and moist pacific air penetrating inland through wide valleys in the Coast ranges. Specifically. the study area was located in the broad valleys of the Skeena / Bulkley river system which provide a region influenced by climates transitional between the coastal systems to the west and the continental systems in the east. This transitional climatic zone is unique in British Columbia where the steep coastal mountain ranges provide few opportunities to study peatlands in non – alpine or subalpine transitional regions.

Five peatlands were located along this gradient, with Butze Rapids Bog and Green River Bog near Prince Rupert in the coastal zone, Powerline Bog and Highway Bog near New

Hazelton in the transitional zone, and Adamson Bog near Telkwa in the continental zone (Figure 3-1; all unofficial names). In order to maintain developmental consistency across regions, all selected sites were ombrotrophic, raised bogs.

The coastal climate is expressed in the Coastal Western Hemlock BGCZ. Both coastal sites (Butze Rapids and Green River Bogs) are located in the very wet hypermaritime (CWHvh2) subzone, which has a mean annual precipitation of 2951 mm and a mean annual temperature of 8.2°C (Klinka et al. 1991). The peatlands studied in this zone are dominated by dwarf *Pinus contorta* var. *contorta* and *Thuja plicata* trees with *Sphagnum austinii*, *Racomitrium lanuginosum*, and *Cladina* spp. in the ground layer. Surrounding upland forests are characterized by *Chamaecyparis nootkatensis* , *Thuja plicata*, and *Tsuga heterophylla* (Pojar et al. 1991).

The region of transitional climate is recognized by the Interior Cedar – Hemlock BGCZ (Figure 3-1). The closest long-term weather station (Hazelton Temleham; 55°12'N, 127°44'W, 121.9 m above sea level) located approximately 5km to the southwest of Highway and Powerline Bogs has a mean annual precipitation of 614 mm and a mean annual temperature of 4.8°C (Environment Canada 2002). The regional climax vegetation is forests of *Tsuga heterophylla*, and *Thuja plicata* (Haeussler et al. 1985). The two peatlands in the Interior Cedar – Hemlock Zone are dominated by *Picea mariana*, with a dense shrub layer of *Ledum groenlandicum* and ground layers of *Pleurozium schreberi* and *Sphagnum fuscum*.

Continental climate occurs along the transect in the Sub – Boreal Spruce BGCZ (Pojar et al. 1984). The single site in this zone (Adamson Bog) is found in the dry, cool (SBSdk) subzone where the mean annual precipitation is 467 mm and the mean annual temperature is 3.1°C (Meidinger et al. 1991). In this region, the dominant upland tree species are *Picea glauca* x *engelmannii*, *Pinus contorta* var. *latifolia*, *Populus tremuloides* and *Populus balsamifera* (Meidinger et al. 1991). The one peatland studied in this zone was dominated by a *Picea mariana* forest with an understory of *Ledum groenlandicum* and a ground layer of *Sphagnum angustifolium*, *Sphagnum fuscum*, *Pleurozium schreberi*, *Hylocomium splendens*, and *Ptilium crista-castrensis*.

Not only does this transect encompass a range of climates, but the surficial geology is also variable. Butze Rapids bog is formed directly in a bedrock depression but all other sites are underlain by Quaternary mineral deposits formed over the regional bedrock. Green River Bog lies in a depression in an alluvial terrace of sands and gravels (Clague 1984). Powerline Bog also lies in a shallow channel scar of a sandy alluvial plain, while Highway Bog developed in a depression in the ground moraine, overlain by a sandy glaciofluvial veneer (Clague 1984). Adamson Bog lies in a depression in the glacial drift covering the floor of the Bulkley Valley (Leach 1907; Armstrong 1944). Despite variations in bedrock, all formations are comprised of generally acidic rock types (Sutherland Brown 1960; Hutchinson 1982; Gottesfeld 1985).

METHODS

Field Methods

In each peatland, 2-3 peat cores were extracted in the deepest portions (as determined by probe transects), using a modified Macaulay peat auger with an inside diameter of 5cm. Core sections were stored in 5 cm diameter half sections of 0.5 m to 2 m plastic ABS (Acrylonitrile-Butadiene-Styrene) pipe and wrapped with plastic (Sunspun®) film for transport from the field. Cores A and B were taken from Butze Rapids Bog, C, D, and E from Green River Bog, F and G from the Highway Bog, H and I from Powerline Bog and cores J, K, and L from Adamson Bog.

Peat Core Analysis

The deepest peat core from each bog was sub-sampled every 10 cm, or more frequently with changes in the peat stratigraphy. At each depth, two samples were extracted from semi-frozen peat, using a brass cork borer with an inner diameter of 1.8 cm. To prevent contamination from coring equipment, both ends of the peat sample were removed, resulting in samples of volumes ranging from 1.5 - 5.3 cm^3. One sample was used for physical analysis, the other for macrofossil identification.

Samples extracted for physical analysis were dried to a stable weight at 70°C and BD was determined as the dry weight per unit volume. The non-organic components of the peat were determined through loss on ignition for four hours at 550°C (Dean 1974; Heiri et al. 2001). Ashless BD (BD_a = organic matter density) was calculated by subtracting the weight of the non-organic ash from the BD. Because mineral constituents of the peat are generally low in C and have a higher density than organic matter, there is a greater correlation between peat C content and BD_a than with uncorrected BD (Vitt et al. 2000). For this reason all analyses in this chapter will be conducted with BD_a. Unfortunately, as the ash content of the peat increases, mineral material begins to take up a substantial portion of the peat volume, and BD_a becomes increasingly dependant on the mineral composition of the sample, rather than on the structure of the organic material forming the peat. In the interests of consistency, this study is limited to true peat soils defined as containing less than 30% mineral material by weight (Korhola 1994; Soil Classification Working Group 1998).

The macrofossil samples were analyzed under a dissecting microscope with frequencies estimated as volume percentages from cover estimates of each taxon present. Samples were not sieved and fine organic debris was recorded as a taxon indicative of a difference in peat type and / or decomposition. When degree of decomposition or absence of key features prevented identification of macrofossils to species level, taxa were recorded as broad groups such as "woody roots" or to groups of species such as "section Acutifolia *Sphagnum*" or "*Sphagnum fuscum / rubellum*". Species names follow Douglas et al. (1998) for vascular plants, Anderson (1990) for Sphagna, and Anderson et al. (1990) for other mosses. Appendix I lists macrofossil categories and their identifying features.

From the detailed macrofossil descriptions, six broad categories were created to represent common components thought to influence peat structure. The broad categories used were: Debris, Herbaceous, *Sphagnum*, Brown Mosses, (other) Mosses, and Wood. Details of the macrofossil taxa amalgamated into these six categories are given in Table 3-1 while detailed macrofossil diagrams for the peat cores can be found in Appendix II. The debris category represents highly decomposed organic remains with no discernable cellular structure and would generally be removed by sieving prior to macrofossil analysis (Janssens 1990). Herbaceous remains consist of both above – and below – ground portions of herbaceous vegetation, including material identified to the Cyperaceae family and Pteridophyta subkingdom (Table 3-1). *Sphagnum* remains include material identified to the peat moss genus *Sphagnum* (Table 3-1). Brown moss remains include a number of bryophyte species commonly found in moderate – rich to extreme – rich fen conditions. Specific brown moss species included here are: *Calliergon giganteum*, *Calliergon trifarium*, *Campylium stellatum*, *Drepanocladus aduncus*, *Hamatocaulis vernicosus*, *Limprichtia revolvens*, *Meesia triquetra*, *Scorpidium scorpioides*, and *Tomentypnum nitens* (Table 3-1). The mosses category encompasses those bryophyte species not included as *Sphagnum* or brown mosses and, as a result, is a rather synthetic category including *Bryum* sp., *Racomitrium lanuginosum*, *Polytrichum strictum*, *Dicranum* sp., *Hylocomium splendens*, *Pleurozium schreberi*, and *Ptilium crista-castrensis* (Table 3-1). Wood is also a fairly broad category, including roots and twigs of woody plants along with more substantial woody stem fragments (Table 3-1).

Macrofossil assemblages were also grouped into general peat type classifications (Chapter 2). These analyses resulted in ten peat types but exclusion of samples with greater than 30% ash eliminated both the Mineral and Lake / Shallow Water groupings. The eight remaining peat types consist of two purely coastal types, the Oceanic Fen / Bog (OFB), and the Oceanic Poor Fen (OPF), one pure Bog (B), an intermediate Poor Fen / Bog (PFB), a Poor Fen (PF), a Moderate – Rich Fen (MRF), an Extreme – Rich Fen (ERF), and a somewhat indeterminate Herbaceous Fen (HF) peat type. The HF peat was dominated by herbaceous material and lacked bryophyte indicator species to place it more specifically along the ombrotrophy – minerotrophy gradient.

Radiocarbon Dating

Basal ^{14}C AMS (accelerator mass spectrometry) dates were obtained for each core with the base of peat initiation defined as the lowest point in the core where organic matter accounted for at least 70% of the peat dry weight (Korhola 1994). After preliminary analysis of the macrofossil samples, further dates were obtained at important peat type boundaries within the cores. Although only calibrated ^{14}C dates are used in the text of this chapter, in Table 3-2 both conventional and calibrated dates are provided so that results of this study can be more easily compared with chronologies using radiocarbon years rather than calendar years. The dates were converted to calendar years using the standard calibration data set IntCal04 (Reimer et al. 2004) in CALIB (Stuiver and Reimer 1993) rev. 5.0. A single value was determined for each sample using the probability distribution to determine a weighted average following the recommendation of Telford et al. (2004).

Data Analyses

Carbon Accumulation

Cumulative dry peat mass (g cm^{-2}) was calculated on an individual core basis from the bulk density profiles, using an incremental approach. Increment boundaries were calculated as the midpoints between samples, and dry mass was calculated for each increment as the product of BD$_a$ and increment thickness (see equation 3.1).

$$M_c = \sum_{i=1}^{n} BD_{ic} * w_{ic} \qquad (3.1)$$

Where M_c is the cumulative dry peat mass of core *c*, with *n* increments. BD_{ic} represents the ashless bulk density of increment *i* in core *c* and w_{ic} is the thickness of increment *i* in core *c*.

Peat C mass was calculated from dry peat mass using an ashless peat C content of 51.8% established for continental western Canada (Vitt et al. 2000) which is identical to that determined from calculations of published values from north coastal British Columbia (Turunen and Turunen 2003). The long term apparent rate of C accumulation was calculated as the cumulative mass of C divided by the basal peat age.

Response Surfaces

Three dimensional response surfaces were calculated for the six composite macrofossil categories in relation to depth and BD$_a$ gradients across three climatic zones. Grid nodes were located at BD$_a$ increments of 0.01g cm^{-3} and at depth increments of 10 cm. A distance weighted mean abundance value was calculated for each grid node using all data points within three grid nodes of the selected node following the procedure of Gignac et al. (1991a). The weighted averaging procedure provides a measure of interpolation, lowering the impact of data gaps and smoothing the surface between nodes, while also extrapolating the response surface range by one grid node (Gignac et al. 2004). This analysis was conducted using the SAS statistical package (SAS Institute Inc. 1999).

RESULTS

Peat and C Accumulation

Long Term Apparent Rates of Peat and C Accumulation

Long term apparent rates of C accumulation ranged from 13.9 to 32.6 g C m^{-2} yr^{-1} with an average of 19.9 ± 1.3 (SE) g C m^{-2} yr^{-1} (Figure 3-2A). Greatest variation was observed in the coastal region, where both maximum and minimum LORCAs were observed. Apart from increased variability in coastal peatlands, there are no distinctive trends in LORCAs between climate regions (Figure 3-2A).

Long term apparent rates of vertical peat accumulation ranged from 0.291 to 0.645 mm yr^{-1} with an average of 0.380 ± 0.028 (SE) mm yr^{-1} (Figure 3-2B). Despite findings of the greatest vertical peat growth rate in the coastal region and the lowest rate in the interior region there is no obvious trend in long term vertical peat growth rates between the climate regions (Figure 3-2B).

Basal radiocarbon dates indicate that of the five peatlands examined, the oldest began peat accumulation in the transitional climatic region 9910 cal. yr BP, and the youngest initiated 8410 cal. yr BP in the coastal region (Table 3-2). The greatest variation in basal peat dates is found in cores from the coastal climate zone where the youngest date (4690 cal. yr BP) is found in a subsidiary basin of Green River Bog (core E).

Cumulative Peat C Mass

Limited within core dating control demonstrates an approximately linear relationship between peat age and cumulative peat mass for the cores in regions of interior and transitional climates (Figure 3-3B,C). Cores from the two coastal peatlands show indications of different peat accumulation patterns and a concave relationship is evident in core A, demonstrating declining rates of peat accumulation over time (Figure 3-3A).

Although overall, cumulative peat mass has a linear relationship with age in Core C, deviations from this trend indicate periods of faster and slower peat accumulation over time, with particularly rapid accumulation between 3250 and 2830 cal. yr BP (Figure 3-3A).

Factors Influencing Bulk Density

Depth

Plots of BD_a with peat depth illustrate increasing BD_a with depth in cores from Butze Rapids, Green River, and Powerline bogs (Figure 3-4). Cores from Highway and Adamson bogs, however, only show increasing BD_a with depth in shallow peat. Beyond a depth of approximately 70 cm, the trend reverses and as peat depth increases, BD_a declines (Figure 3-4).

Peat Type

Ashless BD is seen to vary among peat types (Figure 3-5A) and when samples from all cores are examined together, there is a general trend of increasing BD_a from ombrotrophic to minerotrophic peat types. The more ombrotrophic peats (OB, PFB, B, and OPF) have lower values of BD_a while the more minerotrophic peats (ERF and MRF) are associated with the highly variable PF and HF types and have higher BD_a values (Figure 3-5A). This pattern is consistent across climate zones when each of the three zones is considered independently (not shown). Although containing only two samples, the OFB peat type contradicts the prevalent trend, having the highest BD_a, despite being an ombrotrophic peat type (Figure 3-5A).

A complication also arises from the, tendency of BD_a to increase with depth in many of the peat cores (Figure 3-4). The ombrotrophic peats, which have lower BD_a values, also occur at shallower peat depths (Figure 3-5B). While trends with depth cannot account for all BD_a variations (see for example the high depth but intermediate BD_a of the ERF and the shallow depth, but high BD_a, of the OFB peat) it is difficult to tease apart these two variables (compare Figures 3-5A & B).

Macrofossil Composition

When samples from all climate zones are considered, Debris content can be seen to increase with both BD_a and with depth in the peat core (Figure 3-6). The same trend is evident in both the coastal and transitional climate zones (Figures 3-7 & 3-8) but in the Interior zone, where the only core does not show a consistent increase in BD_a with depth, it can be seen that debris abundance increases with increasing BD_a and not with increasing depth (Figure 3-9).

The herbaceous content of peat can also be seen to increase with both BD_a and depth in the coastal and interior cores, as well as when all regions are combined (Figures 3-6, 3-7 & 3-9). In the transitional climate zone, herbaceous content increases with BD_a at depths shallower than about 200 cm while, in deeper peat, high herbaceous content is associated with intermediate BD_a values (Figure 3-8).

High *Sphagnum* content is associated with shallow peat depths and low BD_a in the combined data set, as well as in all three climate regions individually (Figures 3-6 to 3-9). The only exception is one sample dominated by *Sphagnum teres* in the transitional climate zone, causing an anomalous peak abundance at intermediate levels of BD_a (Figure 3-8). In deeper peat, where the samples are not dominated by *Sphagnum*, intermediate levels of BD_a are associated with the occurrence of *Sphagnum* (Figures 3-7 & 3-8).

Bryophytes included in the mosses category, although more abundant at shallow peat depths, are consistently found in peat of moderate BD_a (Figures 3-6 to 3-9). The exception is found in the transitional climate region where the highest abundance of the mosses peat type is found in surface peat with low BD_a (Figure 3-8).

Brown mosses are found only in moderately deep to deep peats and are associated with moderate to high levels of BD_a (Figure 3-6). Brown mosses are entirely absent from coastal peats (Figure 3-7) and in the interior climate zone, are associated with moderate levels of BD_a at intermediate depths (Figure 3-9). In the transitional climate zone, two peak abundances illustrate the range of BD_a (Figure 3-8).

In both the transitional climate region and in the combined data set, wood content increases with increasing BD_a and, although quite variable, no trend is evident with depth (Figures 3-6 & 3-8). In the coastal zone, a slight increasing trend is evident with both depth and BD_a but woody remains only occur at very low abundances (Figure 3-7). In the interior zone, there is also a trend of increasing BD_a associated with higher abundances of woody remains and, although the highest abundances of wood occur in shallow peat, there is no consistent trend in woody abundance with depth (Figure 3-9).

DISCUSSION

Peat and C Accumulation

Long Term Apparent Rates of C Accumulation

The mean LORCA (19.9 g C m^{-2} yr^{-1}) calculated for peatlands of west – central British Columbia compares well to other estimates, from northern peatlands, of 17.2 g C m^{-2} yr^{-1} (Turunen et al. 2001), 22.3 g C m^{-2} yr^{-1} (Mäkilä 1997) and 20.6 g C m^{-2} yr^{-1} (Tolonen et al. 1992). However, accumulation rates of individual cores are generally lower than the average value of 29 g C m^{-2} yr^{-1} determined by Gorham (1991) and 32.3 g C m^{-2} yr^{-1} (calculated from 62.1 g m^{-2} yr^{-1} Zoltai 1991) using primarily values from interior North America. This discrepancy is likely due to the age difference as peatlands did not begin to form in many areas of North America until 4000 or 5000 years ago (Zoltai 1988) while the average age of cores used in this study was 8310 cal. yr BP. The only core with a LORCA greater than 21.5 g C m^{-2} yr^{-1} was noticeably younger than the rest, with an age of 4690 cal. yr BP and a LORCA of 32.6 g C m^{-2} yr^{-1} (Figure 3-2). No differences in LORCAs between climatic zones were observed despite suggestions in the literature of low LORCAs in peatlands along the West Coast of North America and a trend of declining LORCAs with increased precipitation (Gorham et al. 2003; Turunen and Turunen 2003). The smallest LORCA found in this study was more than double the 6.3 g C m^{-2} yr^{-1} recorded by Turunen and Turunen (2003) although coastal accumulation rates were quite comparable to the 17.2 and 32.3 g C m^{-2} yr^{-1} reported from Pleasant Island in the Alaskan panhandle (Gorham et al. 2003). The greatest variability in LORCAs was observed in the coastal region and the two peatlands examined were raised bogs, while soligenous poor fens are the dominant peatland type in north –

coastal British Columbia (Vitt et al. 1990). More data from a greater variety of peatland types is needed in order to determine a typical LORCA for peatlands in the coastal wetland region.

Long Term Apparent Rates of Vertical Peat Accumulation

The mean long term apparent rate of vertical peat accumulation (0.380 mm yr^{-1}) determined for west – central British Columbia bogs is well within the ranges of vertical peat growth reported for peatlands in Finland, Siberia, and North America (Ovenden 1990; Mäkilä 1997; Turunen et al. 2001; Gorham et al. 2003). No differences were observed in vertical peat accumulation rates between climate zones. The rates of vertical peat accumulation found in the coastal climate region are, however, all more than double the rate of 0.15 mm yr^{-1} recorded by Turunen and Turunen (2003) for a slope bog in the same region. Other rates from the West Coast of North America (0.18 and 0.38 mm yr^{-1}; Gorham et al. 2003) are intermediate between the low rate of Turunen and Turunen and the rates observed in the coastal peatlands of this study which range from 0.346 to 0.645 mm yr^{-1}.

As with the LORCA, the greatest vertical peat growth rate is found in the youngest peat core and likely reflects difficulties in comparing apparent rather than actual rates of peat accumulation (Tolonen and Turunen 1996). Actual rates of accumulation must be modelled and give the instantaneous rate of accumulation while apparent rates are always lower with age, reflecting the increased decomposition in the catotelm over time (Tolonen and Turunen 1996).

Fire History Influences

While apparent rates of both C and peat accumulation fail to account for long term catotelm decomposition (Tolonen and Turunen 1996; Clymo et al. 1998), and are thus increasingly biased with peat age, these rates also ignore any losses of peat due to fire. In continental western Canada, fire has been shown to significantly impact long term accumulation rates, and when peat losses due to fire were incorporated, the peat accumulation rate, corrected for long term catotelm decay, was seen to rise by 26% from 19.4 ± 2.1 to 24.5 ± 2.4 g C m^{-2} yr^{-1} (Vitt et al. 2000; Turetsky et al. 2002). Fire frequency does differ, however, between the Pacific Maritime and Montane Cordillera ecozones, where the study transect is located, and the Taiga Plains, Boreal Plains, and Boreal Shield ecozones that comprise the forested regions of continental western Canada. The large fire return interval increases from 100 – 200 years, in the ecozones of continental western Canada, to 2500 – 10 000 years in the Montane Cordillera, and Pacific Maritime ecozones of west – central British Columbia (Canadian Council of Forest Ministers 2000). While charcoal – like substances occur sporadically in all cores examined in this study (Appendix IV), no substantial charcoal layers, indicative of ground fires, were identified in any of the cores. This lack of physical evidence, coupled with much higher large fire return intervals than are present in the forests of continental western Canada, indicates that the long term rates of peat and C accumulation have, likely, not been so severely affected by peat combustion as many continental systems.

The Clymo Model of Peat Accumulation

Long term peat accumulation is often described in terms of a conceptually simple model originally proposed by Clymo in 1984. The so-called Clymo model considers peat accumulation in terms of an aerobic surface peat layer (the acrotelm) and an underlying, anaerobic peat layer (the catotelm). Organic matter produced at the peatland surface is partially decomposed under the aerobic conditions of the acrotelm before being transferred to the catotelm where decomposition continues at a much slower rate. Given a constant input of peat from the acrotelm to the catotelm and a constant rate of decay within the catotelm, Clymo (1984; Clymo et al. 1998) predicts a concave relationship between cumulative peat mass and age. While constant rates of input and decay seem unlikely given autogenic succession and changing climate conditions, using profiles dominated by *Sphagnum* peat, Clymo successfully described peat accumulation profiles in oceanic raised bogs of western Europe (Clymo 1984). This concave relationship was shown to be widespread in southern Finland (Clymo et al. 1998) but has been less successfully supported for fens and peatlands in northern Finland, North America, and Siberia (Clymo et al. 1998; Yu et al. 2000; Turunen et al. 2001; Gorham et al. 2003). In a similar manner, the only core to show a concave cumulative peat mass curve (Core A) was found in the coastal region with all interior and transitional zone peatlands exhibiting approximately linear curves (Figure 3-3). Clymo et al. (1998) cautions that the model cannot be expected to describe peat accumulation without a "fairly homogeneous botanical composition" of the peat. Minerotrophic peats found at the base of interior and transitional zone cores clearly violate any assumptions of peat homogeneity and would explain changes in productivity and decomposition over time. While the coastal peatlands do not have uniform peat composition, they do both show *Sphagnum* presence throughout the profiles indicating somewhat similar accumulation conditions, as evidenced by the concave cumulative mass curve of Core A. As a caution, none of the cores examined here have the minimum of eight ^{14}C dates recommended by Clymo et al. (1998) and further dating would be necessary to confirm these trends and to determine input and decay coefficients.

There is also an indication that, in at least one instance, changing climatic conditions have influenced peat accumulation. In core C, a period of rapid accumulation, occurs between 3042 and 2730 yr BP (3250 – 2830 cal. yr BP; Figure 3-3A), coinciding with a cooling and wetting of the climate at 3200 yr BP (Banner et al. 1983; Hebda 1995). It seems likely that the moistening of the climate at this time caused a rise in the peatland water table (Chapter 2) which, effectively, elevated the acrotelm – catotelm boundary. This shrinking of the acrotelm, would act to reduce the time peat spends in the rapid decompositional environment of the aerobic acrotelm before passing into the catotelm. Less decompositional loss in the acrotelm would result in a greater transfer of peat into the catotelm, and violate the constant input assumption of Clymo (1984; Clymo et al. 1998).

Factors Influencing Bulk Density

Depth

Increasing BD with depth is a trend common to many peat cores (ie, Clymo 1984; Nicholson 1989; Kuhry et al. 1991; Kuhry 1994; Belyea and Warner 1996) and is often attributed to increased decomposition at depth, leading to a collapse of structural elements, reducing pore space, and increasing the BD (Clymo 1984). Implicit in this explanation, but not always stated, is the concept that the cumulative mass of peat above a sample aids in compression of the structure, reducing the pore spaces and, in turn, increasing BD. Not all peat cores, however, exhibit such a consistent trend (i.e. Vardy et al. 1997, Turunen and Turunen 2003) and BD variations must be attributed to other factors. Cores from three of the peatlands examined in this study exhibited a general trend of increasing BD_a with depth, although only a slight increase is seen in the profiles from Green River Bog (represented by Core C; Figure 3-4). Adamson and Highway bogs, however, show quite different trends with peak BD_a values occurring at depths of approximately 70 cm and gradually declining BD_a both above, and below the peak (Figure 3-4). As both of these peatlands developed through terrestrialization over limnic peat (Chapter 2) it is likely that they developed from the encroachment of floating peat mats over shallow lakes. A variation of the classic lake - infill model of peatland succession (Crum 1988), floating peat mats may form across a lake surface and gradually thicken until the peat surface is stabilized by the root mat. In such a case, peat would accumulate in situ above the root mat, directly from primary production at the peatland surface. Peat sloughing off below the root mat would infill the old lake basin. Since the surface peat mass is supported by the root mat, any peat sloughed off below the root mat has no force compressing it from above and forms a watery suspension. This successional pattern has long been observed in peatlands along the West Coast of North America (Rigg 1925; Rigg and Richardson 1934, 1938) and, although no BD profiles were presented, zones of watery peat were identified in the central regions of a number of peatlands underlying more solid, surficial peat (Rigg and Richardson 1934, 1938).

Peat Type

Differences in peat types are known to affect both the BD and C density of peat (Nicholson 1989; Beilman 2001; Bauer 2002; Bauer et al. 2005). Results from this study indicate lower values of BD_a in coastal and ombrotrophic peat types but because these peat types also occur at shallower depths, it is not possible to conclusively separate the influences of peat type from those due to compression and increased decomposition with depth. There are indications, however, that the species composition of peat does influence the peat BD. In this study, most coastal and ombrotrophic peat types contain large mounts of *Sphagnum* species, which are associated with lower BD_a (Figure 3-6). However, the two samples that form the OFB peat type, and are dominated by *Racomitrium lanuginosum*, a pleurocarpous species structurally more similar to brown mosses than to *Sphagnum*. This OFB peat type has a much higher BD_a than the other coastal, or ombrotrophic, peats (Figure 3-5A).

Macrofossil Composition

Because response surfaces allow the consideration of three variables simultaneously, BD_a can be examined relative to both depth from the peatland surface and the abundance of specific macrofossil categories. Through the inclusion of debris content as a macrofossil category indicative of relative peat decomposition, it is also possible to examine to what degree trends in BD_a with depth are due to peat decomposition.

Peat Decomposition

Debris content is unique among the macrofossil categories considered in that it, by definition, is a measure of the amount of fine-grained organic material, decomposed beyond a level where it can be identified. Thus, debris content reflects the level of decomposition of a peat sample while all other macrofossil categories represent actual taxa directly reflective of the vegetation type involved in the peat formation. In all climatic zones, higher debris content is associated with higher ashless bulk densities and, in both the coastal and transitional zones, debris content also increases with depth (Figures 3-6 to 3-9). In the interior zone, where BD_a does not increase with depth, the two variables can be separated and debris content is more strongly tied to the BD_a (Figure 3-9). This separation allows functional relationships to be inferred, indicating that the more highly decomposed peat has greater BD_a values and that deeper peat is often more highly decomposed. This agrees with published results of increased peat humification associated with high BD in deeper peats (Aaby and Tauber 1974, Belyea and Warner 1996).

Vegetative Composition

General trends identified from the response surfaces indicate that BD_a increases with both herbaceous content and peat depth while high *Sphagnum* abundance is associated with low BD_a, surface peat layers. High wood content is associated with high levels of BD_a and while brown mosses were only found in deeper peat, they are associated with moderate to high levels of BD_a.

Since mosses is a synthetic category, comprised of various bryophyte taxa that do not fall into the categories of *Sphagnum* or brown moss, one might expect to see relationships to BD_a on an individual core basis where one species dominates the category but not over multiple cores, which may contain different species. In the interior / transitional cores, the dominant taxa of these mosses is *Pleurozium schreberi* while in the coastal cores, *Hylocomium splendens* , *Pleurozium schreberi* and *Racomitrium lanuginosum* are all present. These dominant moss taxa are all robust pleurocarpous mosses commonly found in uplands or dry peatland microsites (Gignac et al. 1991b; Schofield 1992), and, as such, there is reason to believe they would all influence the BD_a in a similar manner. In Highway and Adamson Bogs, *Pleurozium* is only an important component of the peat in the top 20 cm of the cores and thus provides an indication of the lower BD_a values found in the poorly decomposed surficial peat of interior and transitional regions (Figures 3-8 & 3-9). In the coastal zone, the mosses group occurs sporadically throughout the cores but all occurrences are associated with moderate values of BD_a (Figure 3-7).

For the most part, macrofossil response surface trends are consistent across climatic zones and with limited data (only one or two peat cores per climate zone) subtle differences are likely attributable to the restricted data set, rather than restricted ranges of macrofossil taxa. For example, it is unlikely that brown mosses in the interior climate region occur only in such a narrow range of depths and bulk densities as displayed in Figure 3-9. It is also likely that, despite indications of consistently low levels of woody remains in the coastal peats examined here, woody peat is commonly found in the Pacific Oceanic Wetland Region (Banner et al. 1988). One exception should be noted, however, as the absence of brown mosses in coastal zone cores is justified given that brown moss species are absent or rare in surface peatland vegetation of the oceanic region (Gignac et al. 1991b).

SUMMARY AND CONCLUSIONS

Despite indications that, in North America, long term apparent rates of C, and peat accumulation are inversely correlated with mean annual precipitation (Gorham et al. 2003), no trends in either vertical peat accumulation or LORCAs were detected along a gradient from coastal to continental climate zones in west – central British Columbia.

The gradient studied represents a variation of mean annual precipitation from 2951 to 467 mm which is almost identical to the gradient of 2940 to 450 mm studied by Gorham et al. (2003) mostly in eastern North America. With conflicting results, further studies are necessary to explore the relationship between peat accumulation and mean annual precipitation, particularly in western North America. The extraordinarily low accumulation rates of 6.3 g C m^{-2} yr^{-1} and 0.15 mm yr^{-1} previously recorded, near Prince Rupert, in north – coastal British Columbia (Turunen and Turunen 2003) were also not corroborated by this study. The LORCA (19.9 ± 1.3 (SE) g C m^{-2} yr^{-1}) and rate of vertical peat accumulation (0.380 ± 0.028 (SE) mm yr^{-1}) were typical of those recorded in northern peatlands across North America and Europe (Ovenden 1990; Tolonen et al. 1992; Mäkilä 1997; Turunen et al. 2001; Gorham et al. 2003).

A concave pattern of cumulative peat mass with age was observed in one of the coastal peatlands, tentatively supporting the Clymo model (Clymo 1984; Clymo et al. 1998), with declining rates of peat accumulation over time. However, linear cumulative peat mass curves, typical of the majority of North American peatlands (Gorham et al. 2003) were observed for all other sites providing more evidence that peat accumulation in North America does not proceed in the same manner as for European peatlands. Despite limited dating control, few peat cores exist in North America with the recommended eight dates (Clymo et al. 1998) and none of these are located in central - interior British Columbia or the hyperoceainic regions of north coastal British Columbia and southeastern Alaska. Peatland development along the North Pacific Coast has already been established as a complex process (Neiland 1971; Banner et al. 1986, 1987) and indications are that this complexity also extends to peat accumulation, with climatic factors seen to influence accumulation in one core. More studies, with extensive dating, are required to confirm patterns seen in these western North American peatlands.

Because peat bulk density relates directly to the peat C concentration, understanding of factors influencing peat BD is directly relevant to the understanding of peatland C accumulation. Ashless BD, and thus peat C content, was seen to be influenced by patterns in peatland development, depth from the peatland surface, and the vegetative composition of the peat. Peatlands developing through a process of paludification showed a general increase in BD_a with depth in the peat core. Those peatlands developing via terrestrialization from a floating peat mat overlying a lake showed an increase in BD_a with depth only near the surface while below about 70 cm, BD_a decreased with depth.

Using the abundance of organic debris, as a proxy for the degree of decomposition, BD_a was seen to increase with increasing levels of peat decomposition. Vegetative components were also seen to influence the BD_a and while high *Sphagnum* composition was associated with low BD_a values, high values of debris, woody, and herbaceous remains were indicative of high BD_a. Other bryophyte species, including brown mosses typical of rich fens, were generally found in peat with intermediate BD_a levels.

A simple descriptive analysis of macrofossil response surfaces showed that, not only does the degree of decomposition influence the peat BD_a but differences in constituent peat materials are also important. Because climate change is expected to influence the peatland surface vegetation (Weltzin et al. 2000, 2003), as well rates of primary production (Laiho and Laine 1997; Camill 1999; Laiho et al. 2003) and decay (Gignac and Vitt 1994), any models attempting to describe peatland C dynamics should incorporate at least a basic breakdown of peat components.

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Table 3-1: Individual macrofossil taxa that comprise the general macrofossil groupings used for response surface analysis. Appendix I defines the original macrofossil taxa.

Macrofossil Group	Original macrofossil identification
Debris	debris
Herbaceous	herbaceous remains Cyperaceae seeds Fern sporangia *Carex* cf. *pluriflora* roots Pteridophyta roots
Sphagnum	*Sphagnum angustifolium* *Sphagnum austinii* *Sphagnum fuscum / rubellum / capillifolium* *Sphagnum magellanicum* *Sphagnum magellanicum / centrale* *Sphagnum papillosum* *Sphagnum* sec. Acutifolia *Sphagnum* sec. Cuspidata *Sphagnum* sp. *Sphagnum teres* *Sphagnum warnstorfii*
Mosses	*Bryum pseudotriquetrum* *Bryum* sp. *Dicranum* sp. *Hylocomium splendens* *Pleurozium schreberi* *Polytrichum strictum* *Ptilium crista-castrensis* *Racomitrium lanuginosum* *Racomitrium* sp. unknown bryophyte
Brown Mosses	*Calliergon giganteum* *Calliergon trifarium* *Campylium stellatum* *Drepanocladus aduncus* *Drepanocladus* sensu lato *Hamatocaulis vernicosus* *Limprichtia revolvens* *Meesia triquetra* *Scorpidium scorpioides* *Tomenhypnum nitens*
Wood	woody roots woody stems wood fragments

Table 3-2: Sample characteristics and results of accelerator mass spectrometry (AMS) ^{14}C dating for peat cores from Butze Rapids (A & B), Green River (C, D, & E), Highway (F & G), Powerline (H & I), and Adamson (J, K, & L) bogs. Calibrated ages refer to the probability weighted mean age as calculated from CALIB (Stuiver and Reimer 1993) rev. 5.0 using the standard calibration data set IntCal04 (Reimer et al. 2004). Laboratory designation: AA = University of Arizona; TO = Isotrace Laboratory, University of Toronto.

Lab ID	Core	Depth (cm)	Conventional ^{14}C date (yr BP)	Calibrated age (cal. yr BP)	Maximum calibrated age range (2σ)	Dated Material
AA47691	A	113	765 ± 65	710	561 - 898	*Sphagnum, Racomitrium*
AA47692	A	193	1776 ± 43	1700	1569 - 1819	*Sphagnum*
TO-9266	A	316.5	7610 ± 90	8410	8205 - 8588	wood, *Sphagnum,* herbaceous remains
TO-9267	B	269.5	5440 ± 70	6220	6004 - 6396	gymnosperm wood
AA47693	C	92	2730 ± 45	2830	2754 - 2925	*Sphagnum*
AA47694	C	176	3042 ± 53	3250	3078 - 3370	*Sphagnum, Pinus* needles
AA47695	C	260	5955 ± 53	6790	6666 - 6930	*Sphagnum,* herbaceous rhizome, woody rhizome
TO-9268	C	344.5	7470 ± 110	8270	8024 - 8452	wood, herbaceous remains
TO-9269	D	303.5	7870 ± 100	8730	8457 - 8995	*wood, Sphagnum*
TO-9270	E	305.5	4160 ± 60	4690	4529 - 4837	herbaceous rhizome
TO-9271	F	285.5	8470 ± 80	9460	9278 - 9559	limnic and detrital peat
AA47697	G	195.5	6374 ± 47	7320	7178 - 7422	*Sphagnum, Tomentypnum*
TO-9272	G	285	8590 ± 70	9580	9466 - 9736	limnic and detrital peat
TO-9273	H	376.5	8530 ± 80	9520	9322 - 9692	angiosperm wood
AA47698	I	215.5	4135 ± 54	4670	4523 - 4830	Cyperaceae seeds, dicot leaf fragments, *Sphagnum*
AA47699	I	296	5684 ± 45	6470	6324 - 6631	*Picea mariana* needles, Cyperaceae seeds
TO-9274	I	416.5	8830 ± 80	9910	9627 - 10181	wood, Cyperaceae seeds, *Sphagnum*
TO-9275	J	252.5	6730 ± 60	7590	7490 - 7679	limnic and detrital peat
TO-9276	K	257.5	7930 ± 130	8790	8447 - 9121	limnic and detrital peat
AA47700	L	168.5	4726 ± 55	5460	5322 - 5586	Cyperaceae seeds, Betula seeds, dicot leaf fragments
TO-9277	L	279.5	7770 ± 70	8550	8405 - 8749	limnic and detrital peat

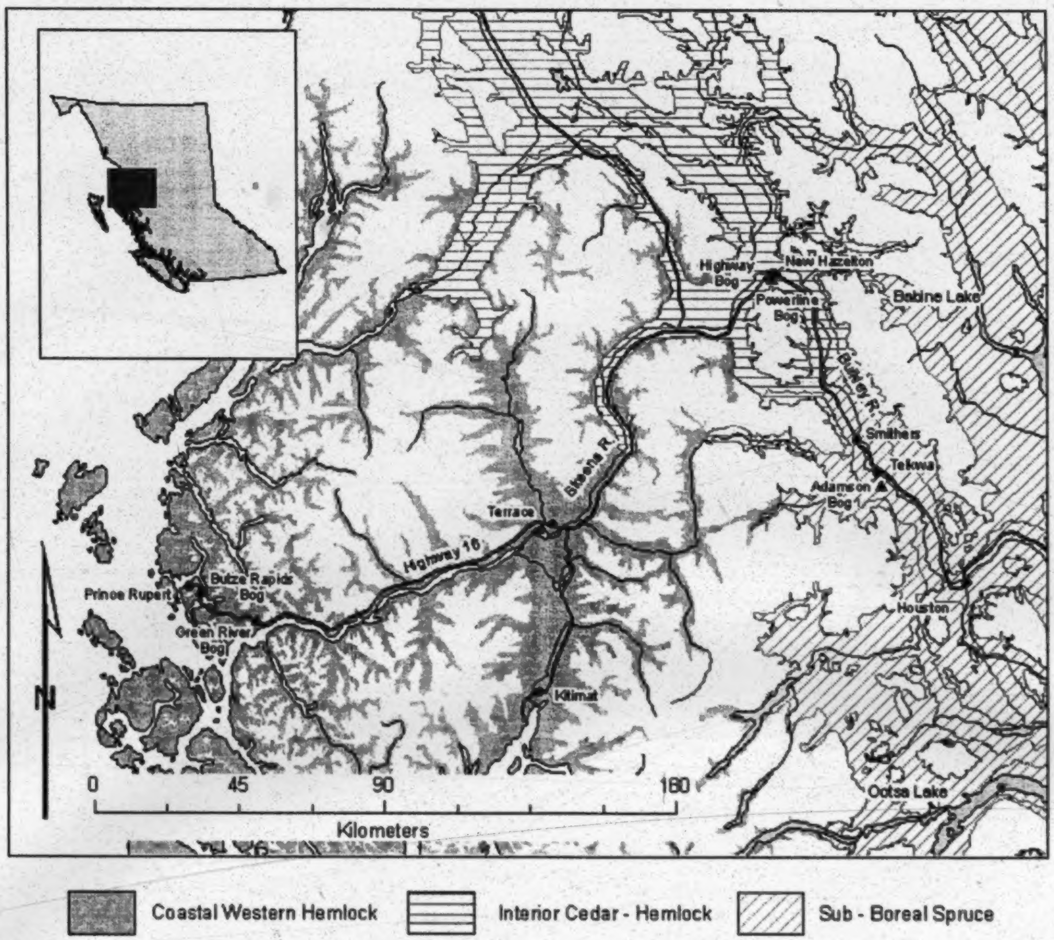

Highway Bog
New Hazelton
Babine Lake
Powerline Bog
Bulkley R.
Smithers
Telkwa
Adamson Bog
Skeena R.
Terrace
Highway 16
Butze Rapids Bog
Prince Rupert
Green River Bog
Kitimat
Houston
Ootsa Lake
N
0
45
90
180
Kilometers
Coastal Western Hemlock
Interior Cedar - Hemlock
Sub - Boreal Spruce

Figure 3-1: Map showing study site locations ▲ and relevant Biogeoclimatic Zones in west – central British Columbia

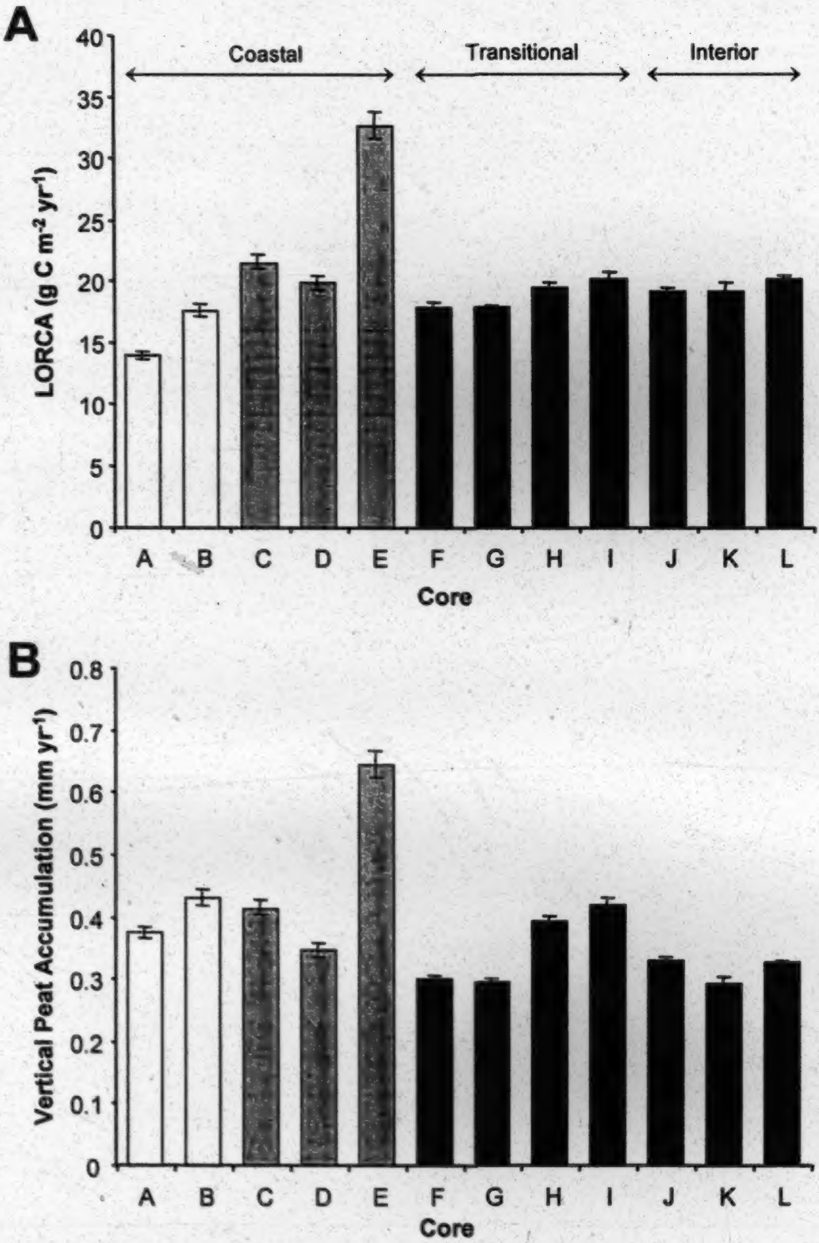


Figure 3-2: Long term apparent rates of A) carbon accumulation (LORCAs) and B) vertical peat accumulation for 12 peat cores from the coastal, transitional and interior climate regions. Shading of bars identifies the five peatlands and error bars represent the minimum and maximum LORCAs as calculated using the 2σ range of ^{14}C calibration errors.

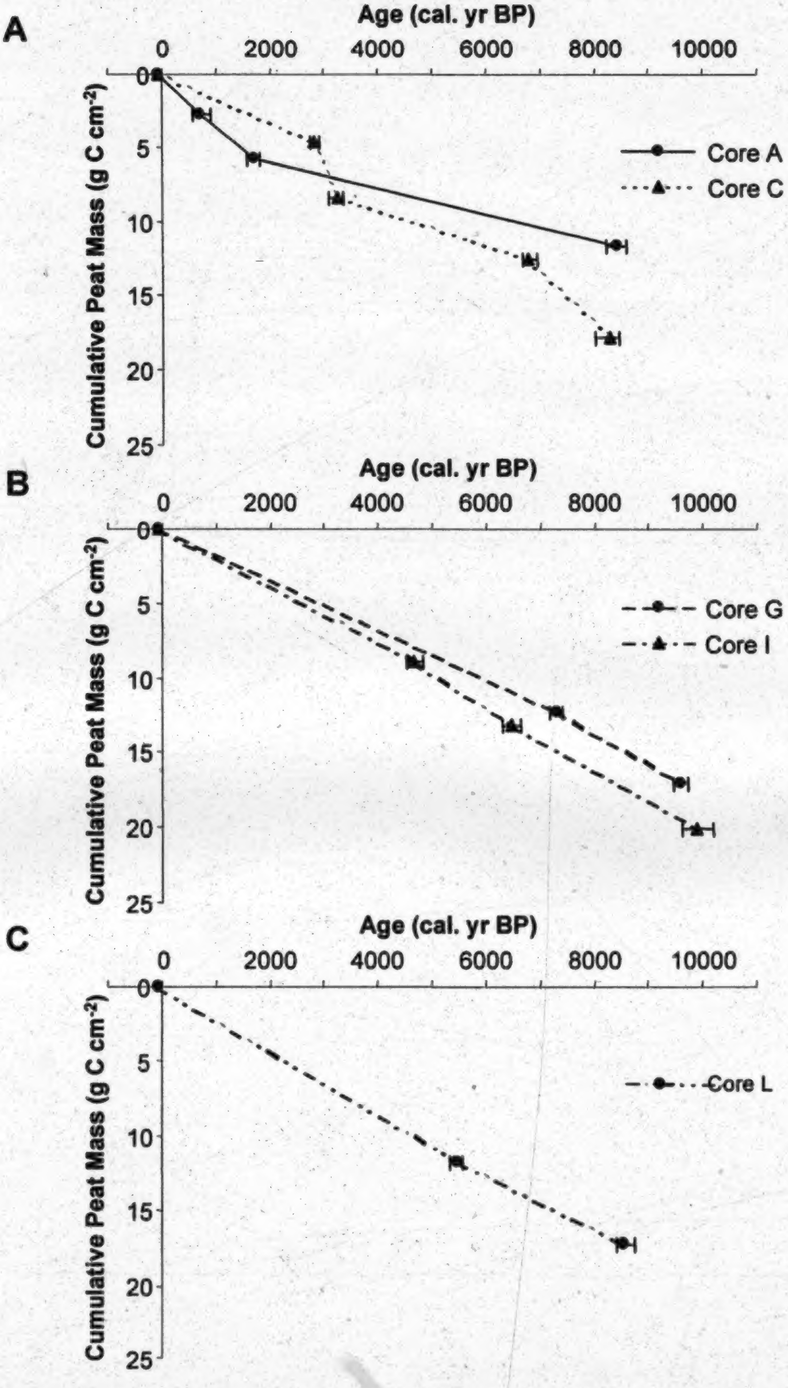
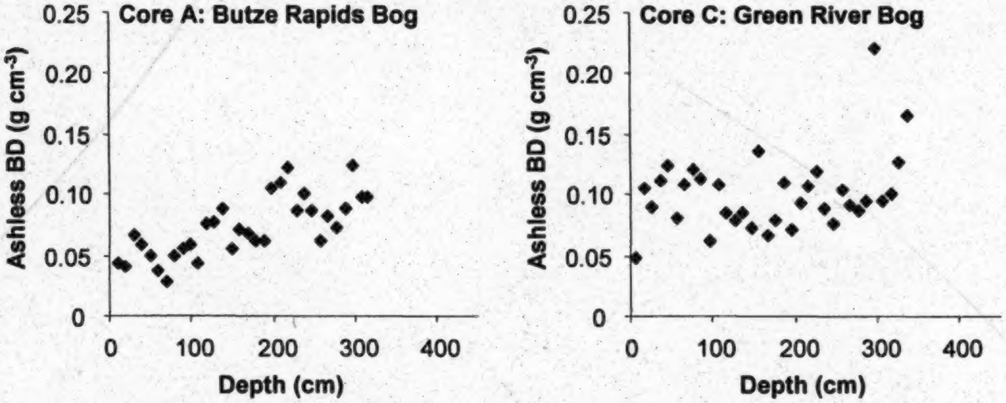
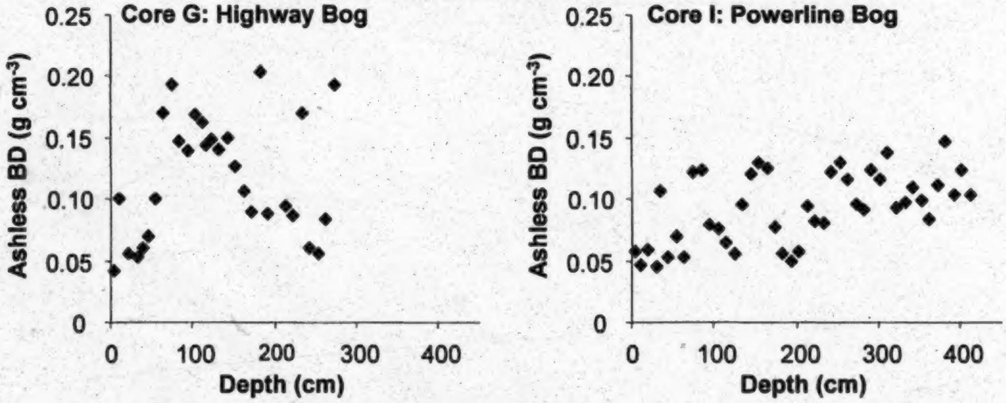


Figure 3-3: Cumulative peat mass below the surface at calibrated ^{14}C dates within peat cores from the A) Coastal, B) Transitional, and C) Interior climate zones. Error bars show the maximum 2σ ranges associated with each calibrated date.

COASTAL



TRANSITIONAL



CONTINENTAL

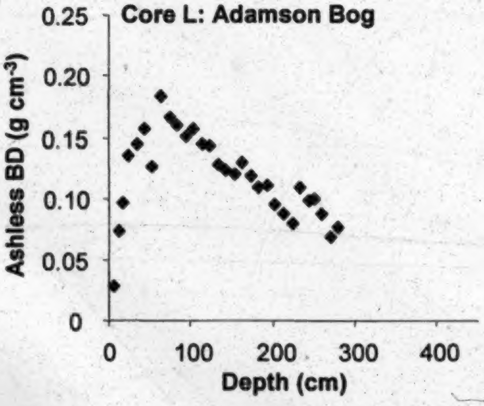


Figure 3-4: Profiles of ashless bulk density with depth for representative cores from each peatland, organized by climate zones.

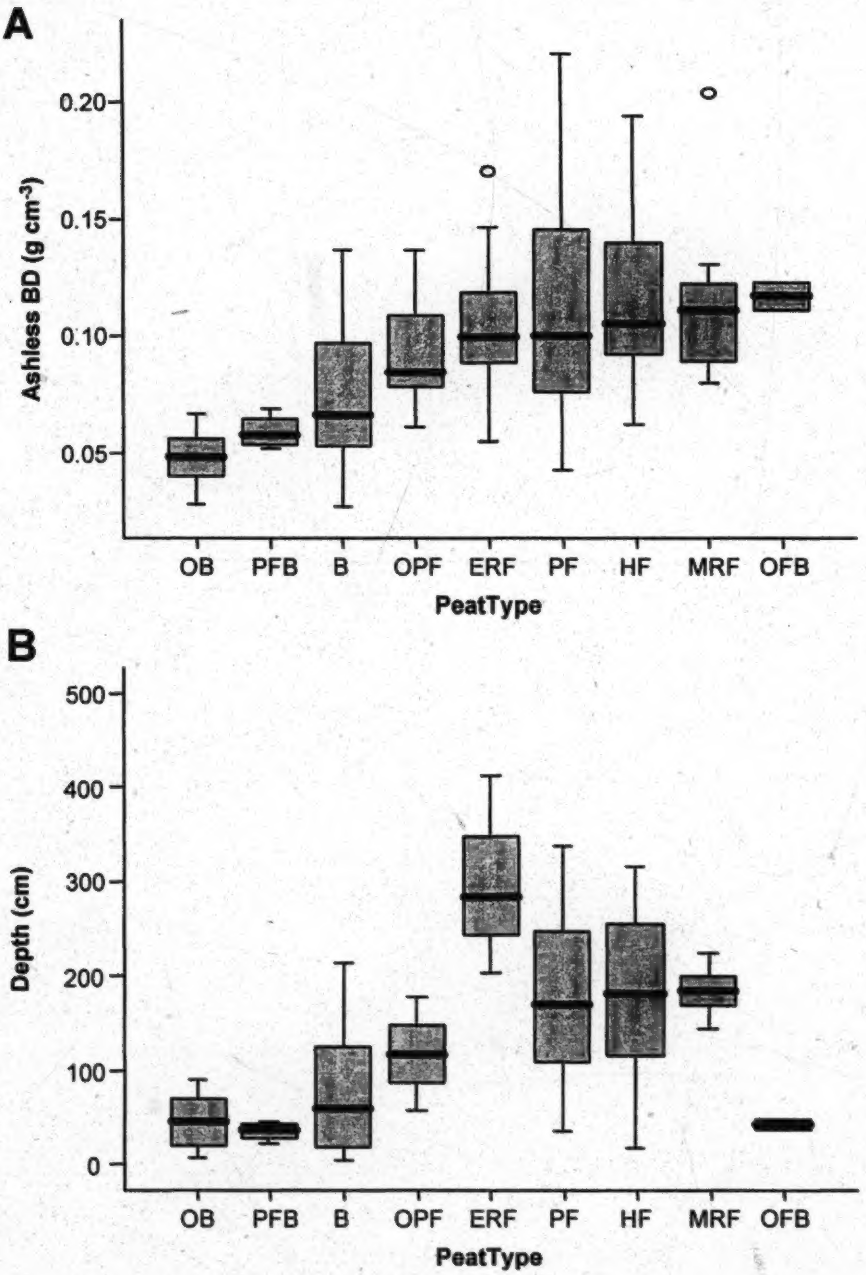


Figure 3-5: Boxplots showing the median A) ashless bulk density and B) depth of various peat types, combining information from all climate regions. Peat types are as follows: OB = Oceanic Bog, PFB = Poor Fen / Bog, B = Bog, OPF = Oceanic Poor Fen, ERF = Extreme – Rich Fen, PF = Poor Fen, HF = Herbaceous Fen, MRF = Moderate – Rich Fen , and OFB = Oceanic Fen / Bog,.

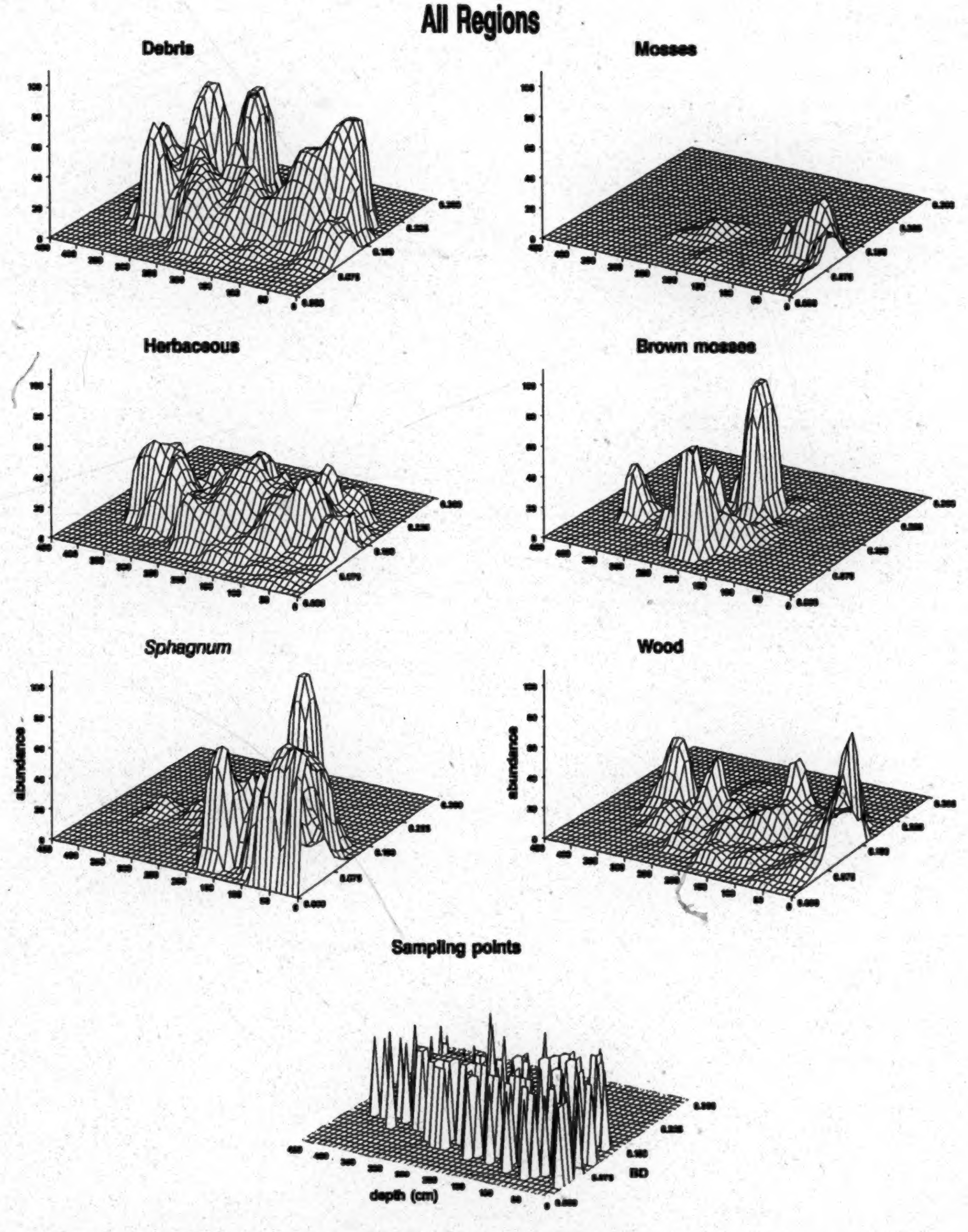


Figure 3-6: Response surfaces for six macrofossil categories along gradients of ashless bulk density (BD; g cm^{-3}) and depth from the peat surface using samples from all climate regions. Sampling points (lower) shows range of conditions over which data is available.

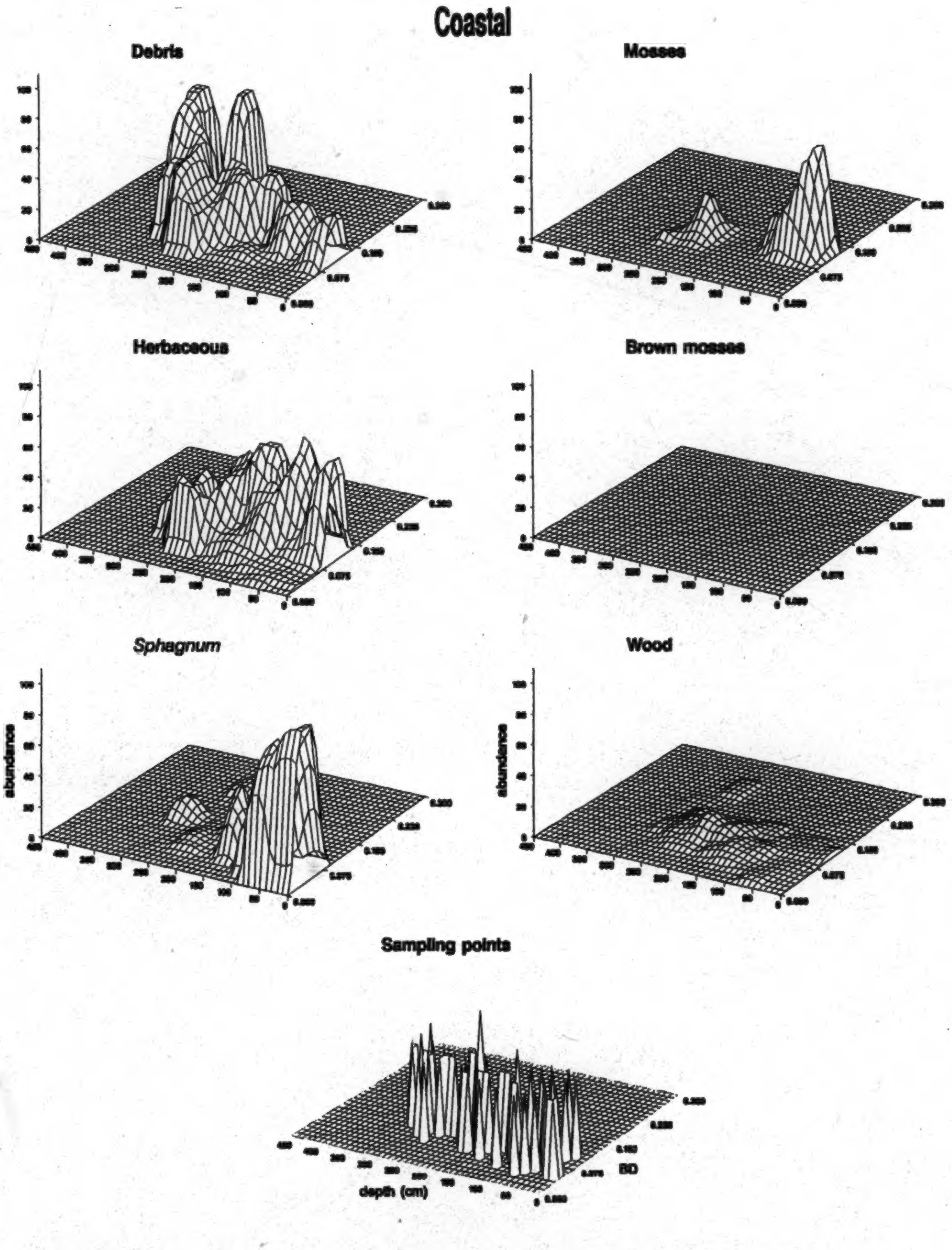


Figure 3-7: Response surfaces for six macrofossil categories along gradients of ashless bulk density (BD; g cm^{-3}) and depth from the peat surface using samples from only the coastal climate region. Sampling points (lower) shows range of conditions over which data is available.

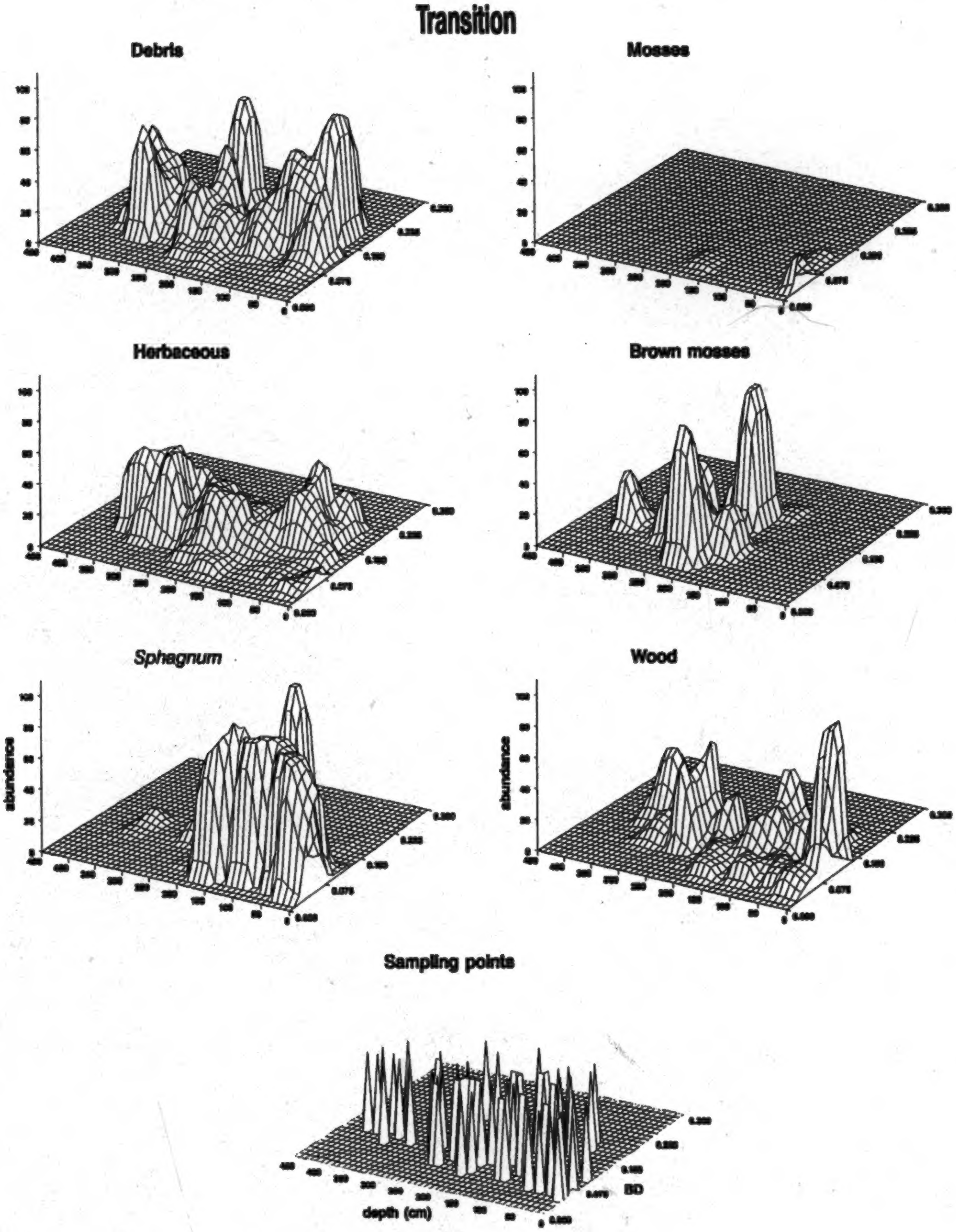


Figure 3-8: Response surfaces for six macrofossil categories along gradients of ashless bulk density (BD; g cm^{-3}) and depth from the peat surface using samples from only the transitional climate region. Sampling points (lower) shows range of conditions over which data is available.

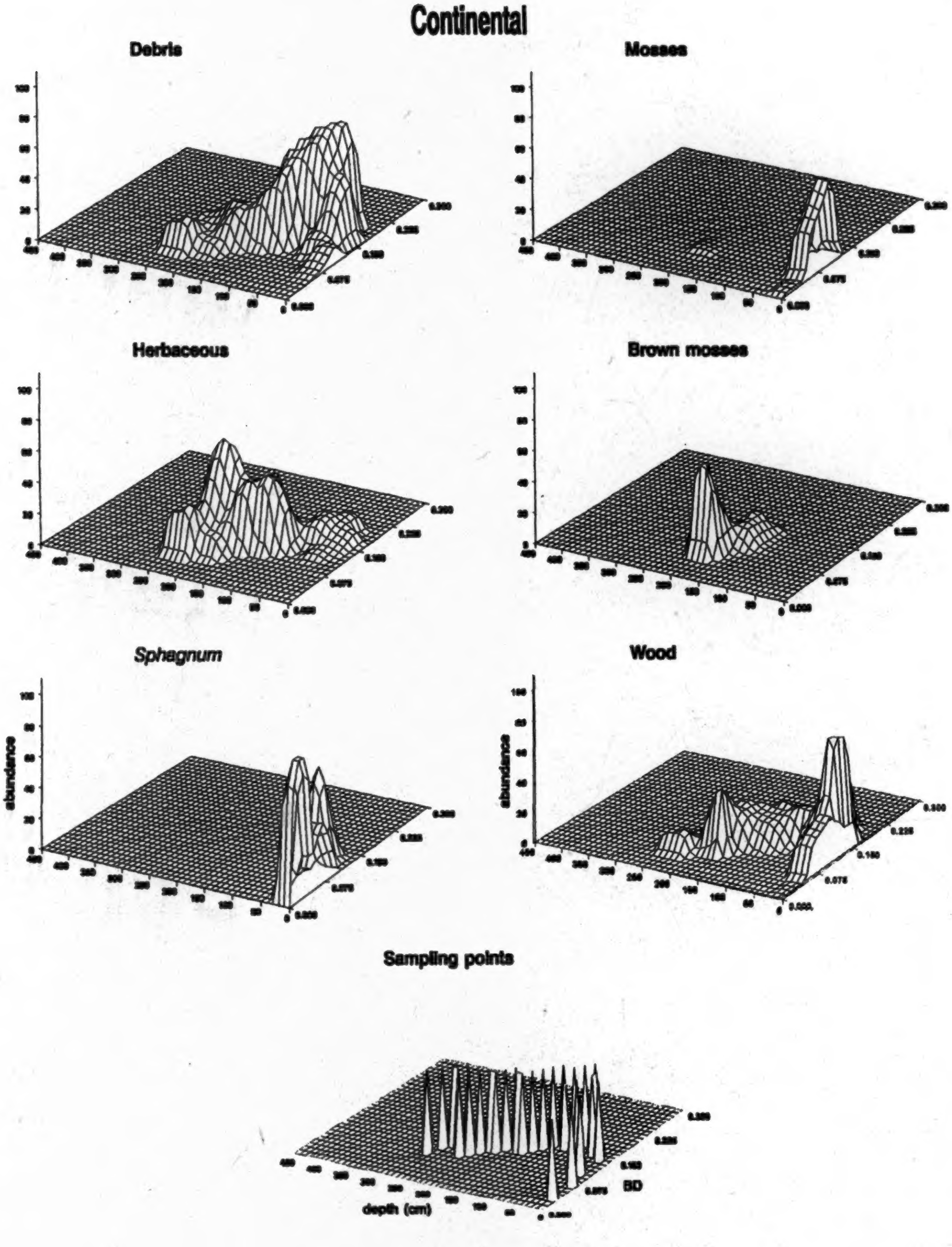


Figure 3-9: Response surfaces for six macrofossil categories along gradients of ashless bulk density (BD; g cm^{-3}) and depth from the peat surface using samples from only the continental climate region. Sampling points (lower) shows range of conditions over which data is available.

CHAPTER 4

Overall Thesis Discussion and Conclusion

Review and Synthesis

This study represents the first inquiry into peatland development and carbon (C) accumulation along a gradient from coastal to continental climates in western North America. Five ombrotrophic raised bogs were examined such that surface vegetation varied primarily along a climatic gradient, represented by the distance from the ocean. Peatlands influenced by the hyperoceanic coastal climate were vegetatively distinct from both the interior peatlands, influenced by continental climate, and from the peatlands occupying a region of transitional climate. Vegetation of the transitional peatlands was more similar to that of the interior bog than to the coastal sites. This vegetation gradient was also reflected in the peatland surface water chemistry, likely due to changes in the precipitation chemistry along the climatic gradient. Coastal precipitation has a higher sodium concentration because of sea salt inputs (Junge and Werby 1958; McColl et al. 1982; Malmer et al. 1992; Blew and Edmonds 1995) but a lower concentration of all other ions, due to the dilution effect with increased precipitation towards the coast (Malmer et al. 1992; Blew and Edmonds 1995).

High levels of precipitation in the coast region also enabled these peatlands to develop directly on mineral soil through paludification while two of the three more inland sites developed over lake peat by terrestrialization. Basal dates of the coastal peatlands (7610 and 7870 ^{14}C yr BP) correspond to the end of the Early Holocene Xerothermic Interval (Mathewes and Heusser 1981) at approximately 7000 ^{14}C yr BP (Hebda 1995). At this point, precipitation increased and temperature cooled slightly, but stayed above present levels, in regions all along the coast from southern British Columbia (Heusser et al. 1985), to south-eastern Alaska (Heusser et al. 1985; Hansen and Engstrom 1996). The interior and transitional peatlands initiated somewhat earlier than the coastal sites at 7930 ± 130, 8590 ± 70, and 8830 ± 80 ^{14}C yr BP. Because two of these sites initiated over limnic peat, the limited moisture of the Xerothermic Interval was not an inhibitory condition and, likely, aided in reducing the lake / pond level and encouraging wetland vegetation. The oldest site did not develop over a water body and most likely initiated as the Xerothermic Interval dried up a shallow marsh, possibly drying up a shallow inlet stream and stabilizing the water flow in the basin.

Allogenic climatic factors are known to be important in influencing both peatland type (Damman 1977; Glaser and Janssens 1986; Vitt et al. 1994) and abundance on the landscape (Halsey et al. 1997). Autogenic processes are known to be of fundamental importance in peatland development (Kuhry et al. 1993; Vitt 1994; Turunen and Turunen 2003). Results of Chapter 2 show that, while climate change appears to have controlled the timing of peat initiation, it was of secondary importance to autogenic processes once peat accumulation was underway. The large volume of precipitation in the coastal region, with concomitant low ion concentration, results in conditions unsuitable for growth of many rich fen bryophyte species (Gignac et al. 1991). In this manner, while development of the interior and transitional sites demonstrated successional sequences along the entire ombrotrophy – minerotrophy gradient from extreme – rich fen, to moderate – rich fen, to poor fen, and then to bog, the coastal peatlands developed along a truncated gradient from only poor fen to bog.

The warming and moistening of the climate at approximately 4000 ^{14}C yr BP, at first appears contradictory to the transition towards poor fen or bog zones at the continental and transitional sites. The transition from high pH, low HAWT rich fens to low pH, high HAWT poor fens or bogs is opposite to what would be expected as the climate becomes wetter. When examined more closely, however, both transitional peatlands show a re-moistening of the peatland surface at this time, delaying the transition towards poor fen or bog zones by approximately 1000 ^{14}C years. In this manner, although autogenic processes drive the general trends seen in peatland development, allogenic climate also influential the peatland vegetation, particularly during the transition from rich fens to poor fens and bogs when the system is highly sensitive to changes in pH.

Despite indications that, in North America, long term apparent rates of C, and peat, accumulation are inversely correlated with mean annual precipitation (Gorham et al. 2003), no trends in either vertical peat accumulation or the long term apparent rate of C accumulation (LORCA) were detected along the strong precipitation gradient in west – central British Columbia. The extraordinarily low accumulation rates of 6.3 g C m^{-2} yr^{-1} and 0.15 mm yr^{-1} previously recorded in north – coastal British Columbia (Turunen and Turunen 2003) were also not corroborated by this study. The LORCA (19.9 ± 1.3 (SE) g C m^{-2} yr^{-1}) and rate of vertical peat accumulation (0.380 ± 0.028 (SE) mm yr^{-1}) were typical of those recorded in northern peatlands across North America and Europe

(Ovenden 1990; Tolonen et al. 1992; Mäkilä 1997; Turunen et al. 2001; Gorham et al. 2003).

A concave pattern of cumulative peat mass with age was observed in one of the coastal peatlands, tentatively supporting the Clymo model (Clymo 1984; Clymo et al. 1998), with declining rates of peat accumulation over time. However, linear cumulative peat mass curves, typical of the majority of North American peatlands (Gorham et al. 2003) were observed for all other sites providing more evidence that peat accumulation in North America does not proceed in the same manner as for European peatlands. Peatland development along the North Pacific Coast has already been established as a complex process (Neiland 1971; Banner et al. 1986, 1987) and indications are that this complexity also extends to peat accumulation, with climatic factors seen to influence rates of peat accumulation in one of the coastal cores.

Ashless BD, and thus peat C content (Vitt et al. 2000), was seen to be influenced by patterns in peatland development, depth from the peatland surface, and the vegetative composition of the peat. Paludified peatlands showed a general increase in BD_a with depth in the peat core while those peatlands developing via terrestrialization from a floating peat mat overlying a lake showed an increase in BD_a with depth only near the surface. Below about 70 cm, BD_a decreased with depth in these lake – infill peatlands.

While general trends in BD_a with depth exist, BD_a was also seen to be influenced by peat composition. High *Sphagnum* composition was associated with low BD_a values, and high values of debris, woody, and herbaceous remains were indicative of high BD_a. Other bryophyte species, including brown mosses typical of rich fens, were generally found in peat with intermediate BD_a levels. Using the abundance of organic debris, as a proxy for the degree of decomposition, BD_a was also seen to increase with increasing levels of peat decomposition. In order to understand how climatic factors influence peatland C accumulation, it is important to consider, not only what vegetation types are forming the peat but also, the pattern of peatland development. Specifically, peatlands initiating from floating mats are seen to have very different profiles of BD_a with depth than the more common paludified peatlands.

Future Research Directions

With only five sites distributed across three broad climatic zones it is impossible to make generalizations about peatland development and C accumulation in those zones. This study, in particular, was limited in application by considering only ombrotrophic, raised bogs. The site selection limited variables across zones, and allowed for a focus on climatic differences, while providing relatively old palaeoecological records. Unfortunately this peatland type is not most prevalent in each climate region. Specifically, the dominant peatland type in north – coastal British Columbia is a soliginous poor fen (Vitt et al. 1990). More studies over a broader range of site types are necessary in order to understand what factors are most influential on peatland development and C accumulation throughout each climate region.

Contrasting results of peatland development studies on the West Coast (Banner et al. 1986, 1987; Neiland 1971), coupled with very different LORCAs and rates of vertical peat accumulation from Chapter 3 and work by Turunen and Turunen (2003) indicate that much more research is needed to understand peatland development and C accumulation in peatlands along the North Pacific Coast of North America. In particular, long term C accumulation has not been studied in the shallow poor fen blanket peatlands that are the most prevalent peatland type in the region (Vitt et al. 1990; Banner et al. 1986).

Additional research is also needed to address conflicting trends in LORCAs along precipitation gradients. While the LORCA was found to decrease with increased precipitation in a North American study (Gorham et al. 2003), no changes in the LORCAs were detected across an equally large precipitation gradient in west – central British Columbia (Chapter 3). Because only one site in the continent – wide study (Gorham et al. 2003) was from the Pacific Coast, and no sites were from continental western North America, future research is needed to spatially expand on the work of Chapter 3 and determine if this trend in LORCAs with precipitation is limited to eastern North America or if it also occurs over a larger geographical area in western peatlands.

While detailed palaeoclimate records were available along the Pacific Coast, only two, contrasting, records document Holocene palaeoclimate in central – interior British

Columbia. In an overview of past vegetation and climate in British Columbia, Hebda (1995) identified this discrepancy and need for further studies but, as yet, no further work has been published in this area. In order to understand how peatlands have responded to past climate changes, detailed palaeoclimate records are necessary. Particularly in British Columbia, where ubiquitous mountain ranges create complex climate patterns, numerous climate records are necessary to determine local palaeoclimate conditions.

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APPENDIX I

Raw Surface Vegetation Data

Table A1-1: Percent cover of surface vegetation species in the 12 circular releve (50 m^2) locations distributed across the five peatlands

	Butze Rapids		Green River			Highway		Powerline		Adamson		
Species	A	B	C	D	E	F	G	H	I	J	K	L
GROUND LAYER												
Aulacomnium androgynum								+				
Aulacomnium palustre						1	2				+	+
Bazzania tricrenata	+											
Brachythecium asperrimum								+		+		
Brachythecium frigidum						+						
Bryum pseudotriquetrum							1					
Calypogeia sphagnicola		+						+	1			
Cephalozia connivens		+	1									
Cephalozia leucantha			+									
Cephalozia loitlesbergeri	+											
Cephalozia macrostachya		+										
Cephalozia pleniceps								+			+	
Cephalozia sp.			+									
Cladina cf. *portentosa* ssp. *pacifica*				40								
Cladina ciliata				2								
Cladina mitis	7	8								+		+
Cladina rangiferina	+	+	24		39			+	+			
Cladina stygia				1	2							
Cladonia carnolea								+	+	+	+	
Cladonia cenotea									+	+	+	
Cladonia chlorophaea						+		+	+			
Cladonia coniocraea												+
Cladonia cornuta											+	
Cladonia crispata		+	+	+	+							
Cladonia furcata	+				+							
Cladonia gracilis	+							+	+	+	+	
Cladonia gracilis ssp. *turbinata*							+					+
Cladonia gracilis ssp. *vulnerata*		+		+	+							
Cladonia multiformis			+		+							
Cladonia sp.									+			
Cladonia squamosa			+									
Cladonia subfurcata				1	+							
Cladonia sulphurina												+
Cladonia uncialis			1	5	2							
Cladopodiella fluitans					+							
Coelocaulon aculeatum			+	+								
Dicranum fuscescens												+

+ represents < 1 % cover

Table A1-1 Cont'd

	Butze Rapids		Green River			Highway		Powerline		Adamson		
Species	A	B	C	D	E	F	G	H	I	J	K	L
Dicranum majus	+											
Dicranum polysetum						+	+					
Dicranum scoparium	+			+		+						
Eurhynchium pulchellum var. *pulchellum*						2						
Frullania nisquallensis	+	+										
Hylocomium splendens	+					+						20
Icmadophila ericetorum												+
Kurzia makinoana			+	+								
Mylia anomala		+	+	+	+			+	1			
Mylia taylorii	+											
Odontoschisma denudatum			+									
Plagiomnium insigne						+	2					
Plagiomnium medium ssp. *medium*						2	+					
Plagiothecium undulatum		+										
Pleurozium schreberi	+	+	+	+	40	10	15	1	1	40	10	10
Pohlia cf. nutans		+										
Pohlia cf. sphagnicola	+	1						+	1			
Pohlia nutans											+	
Pohlia sphagnicola									+			
Polytrichum strictum	1							+				
Ptilium crista-castrensis						1	+	+		1	+	20
Rhacomitrium lanuginosum	1	1	8	10	+							
Rhytideadelphus loreus		+										
Rhytideadelphus triquetrus						1	+					
Riccardia palmata	+											
Scapania bolanderi	+											
Sphagnum angustifolium										51	81	41
Sphagnum austinii	83	87	18	6								
Sphagnum capillifolium	+				4	1						
Sphagnum compactum			1	2								
Sphagnum fuscum	1	+	+	5	1	+		88	90	1	3	
Sphagnum magellanicum							+			+	1	
Sphagnum papillosum					9							
Sphagnum rubellum	+	1	+	2								
Sphagnum tenellum			2	1	+							
Splachnum ampullaceum										+		
Tomenthypnum nitens											+	
Tomenthypnum nitens var. *falcifolium*											+	

+ represents < 1 % cover

Table A1-1 Cont'd

	Butze Rapids		Green River			Highway		Powerline		Adamson		
Species	A	B	C	D	E	F	G	H	I	J	K	L
Dicranum undulatum												+
Cladonia fimbriata												+
Peltigera neopolydactyla												+
Barbilophozia kunzeana												+
Ptilidium ciliare											+	
HERBACEOUS LAYER												
Calamagrostis canadensis									2			+
Carex pleuriflora	2	+			2							
Carex sitchensis		+										
Carex sp.	+	2	2	+	+			2	2		+	+
Coptis trifolia	+		+	+	1							
Cornus canadensis	+	+	+	+				1	2			
Drosera angelica			1	+								
Drosera rotundifolia	+	+	+	+	+			+	+			
Eriophorum polystachion				1	+							
Fauria crista-galli			+									
Gentiana douglasiana	+	+	+	+	+							
Geocaulon lividum								+	+			
Lycopodium clavatum	+	+	+									
Maianthemum dilatatum	+											
Mitella nuda			+									
Platanthera dilatata									+			
Pteridium aquilinum	1	+										
Pyrola chlorantha						+						
Rhynchospora alba			8	1	1							
Rubus chamaemoras	2	3	+			3	5	7	2	15	35	20
Sanguisorba officinalis		+										
Sanguisorba officinalis ssp. *microcephala*	+		+	1	5							
Tofieldia glutinosa	1	+	1	+	1							
Trichophorum caespitosum			4	8	15							
Trientalis arctica	+		+	+	+							
SHRUB LAYER												
Andromeda polifolia	1	+	+	+	+							
Chamaecyparis nootkatensis	12											
Empetrum nigrum	1	2	+		1			10				
Gaultheria hispidula						+	+			1	1	1
Juniperus communis	1	4	1	5	5							
Kalmia mycrophylla ssp. occidentalis					2							
Kalmia polifolia	1	+	1	1								

+ represents < 1 % cover

Table A1-1 Cont'd

	Butze Rapids		Green River			Highway		Powerline		Adamson		
Species	A	B	C	D	E	F	G	H	I	J	K	L
Ledum groenlandicum	2	6	1	1	2	90	93	60	55	20	40	15
Linnaea borealis	+	+							1			
Menziesii ferruginea	+	+										
Oxycocous microcarpus	+	+	+		+	+	+	1	+	+	+	+
Pinus contorta var. *contorta*		2	1	1	2							
Rosa acicularis								+				
Thuja plicata	1	5	4	3	1							
Tsuga heterophylla	1		+									
Vaccinium caespitosum												+
Vaccinium uliginosum	4	1	+	1								
Vaccinium vitis-ideae		+										
TREE LAYER												
Betula sp.						1						
Chamaecyparis nootkatensis		+										
Picea mariana						20	5	7	5	30	13	30
Pinus contorta						4						
Pinus contorta var. *contorta*	1	1	1	3	2							
Pinus contorta var. *latifolia*									+			
Thuja plicata				1								
Tsuga heterophylla						1		+	+			

+ represents < 1 % cover

APPENDIX II

Raw Water Chemistry Data

Table A2-1: Locations and surface water chemistry values for the five study sites

Site	Latitude	Longitude	n	pH^z	Kcorr^{z,y} (μS/cm)	Cl^z (mg/L)	SO$_4^z$ (mg/L)	Na^z (mg/L)	K^z (mg/L)	Ca^z (mg/L)	Mg^z (mg/L)
Butze Rapids	54.31	130.25	2	4.08 (5.27)	14.12 (5.47)	2.27 (0.34)	10.68 (8.49)	21.70 (13.44)	0.69 (0.37)	1.56 (0.42)	0.34 (0.06)
Green River	54.21	129.98	3	4.21 (4.52)	14.27 (8.75)	0.90 (0.13)	1.59 (2.06)	4.57 (3.50)	0.26 (0.06)	0.69 (0.31)	0.39 (0.08)
Highway	55.24	127.63	2	3.50 (4.18)	45.50 (5.79)	2.81 (3.17)	0.74 (0.06)	4.30 (0.79)	1.26 (0.89)	8.28 (1.22)	0.54 (0.31)
Powerline	55.24	127.60	2	5.99 (6.19)	133.78 (51.62)	2.77 (0.67)	3.65 (3.58)	6.41 (0.78)	1.30 (0.11)	19.8 (6.51)	2.87 (1.19)
Adamson	54.67	127.04	3	4.01 (4.40)	37.39 (0.80)	1.03 (0.97)	2.66 (2.95)	9.17 (8.12)	0.82 (0.42)	11.5 (1.91)	3.60 (0.97)

[z] values in parentheses are standard deviations

[y] conductivity standardized to 20°C (Gardiner & Dackombe 1983) and corrected for hydrogen ions (Sjors 1950)

APPENDIX III

Categories Used in the Analysis of Macrofossil Samples

BRYOPHYTES

Because most standard bryophyte identification relies heavily on features of individual leaves or the cellular structure of stems, relatively in tact macrofossils of many genera can also be identified using standard keys. It is only when decomposition has resulted in loss of key features, such as stem leaves or colour, that identification relies on alternative methods, often resulting in the grouping of species.

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Sphagna

Sphagnum spp.

Leaf cells of two types, the larger, hollow, hyaline cells with pores and annular fibrils on the cell surface, each surrounded by a network of the narrower chlorophyllous cells, green when living but appearing brown in macrofossil samples. Stems usually yellowish or white but sometimes brown (as in *S. fuscum* or due to staining by sample debris) and surrounded by a cortex often of larger, clear cells which may strip off and be absent in the more poorly preserved samples. As this category is only used in the case of very poorly preserved material (usually stems with no leaves or branch leaves too poorly preserved to cross-section) stem leaves are always absent and branches are usually not found attached to the stem in the characteristic fascicles.

Sphagnum Section Acutifolia

This category also contains a grouping of *Sphagnum* species, made indistinguishable by a lack of stem leaves and stem cortex, coupled with a brown stem (either due to staining by debris or having the dark stem characteristic of *S. fuscum*). This section is distinguished from other sections of *Sphagnum* by the ovate-lanceolate, non-cucullate branch leaves with chlorophyllous cells triangular in cross-section and more broadly exposed on the inner (adaxial) surface. Although *S. warnstorfii* is part of this section, pore patterns on the branch leaf clearly differentiate it from other members of this section and, consequently, when branch leaves are present it is distinguishable to species, and not included in this category. Individual species most likely included in this grouping are *S. capillifolium*, *S. fuscum*, *S. rubellum*, and possibly *S. russowii*.

Sphagnum Section Cuspidata

This section is distinguished from other sections of *Sphagnum* by the ovate-lanceolate to linear, non-cucullate branch leaves with chlorophyllous cells triangular in cross-section and much more broadly exposed on the outer (abaxial) surface. This section is likely composed primarily of *S. angustifolium* specimens in which the stem leaves were not preserved to confirm the identification to a species level.

Sphagnum angustifolium

Belonging to Section Cuspidata and having small (< 0.8 mm) approximately equilaterally triangular stem leaves. The stem leaves and absence of enlarged stem cortical cells distinguish *S. angustifolium* from other members of Section Cuspidata.

Sphagnum austinii

A *Sphagnum* species belonging to Section Sphagnum, and having the cucullate-concave branch leaves and spiral fibrils reinforcing branch and stem cortical cells, typical of the section. The chlorophyllous cells are equilaterally triangular in cross-section and broadly exposed on the adaxial leaf surface. This species, in particular, is characterized by comb fibril projections on the inner wall of branch leaf hyaline cells.

Sphagnum fuscum (*Sphagnum fuscum / rubellum*)

A grouping of species belonging to the Section Acutifolia that are usually separated on the basis of pigmentation that is lost in the macrofossil samples. The absence of small (≤ 2 μm), strongly ringed pores on the abaxial surface of the branch leaves, non-porose stem cortical cells, and small to moderate (0.8–1.3 mm long), lingulate stem leaves with a broadly rounded apex separate these species from others in Section Acutifolia. *Sphagnum rubellum* also has stem leaves that vary in shape from lingulate to lingulate-triangular and only those plants with the lingulate leaves, that could not be convincingly separated from those of *S. fuscum* were included in this category. Stem leaves of this category were efibrillose although both species commonly have efibrillose stem leaves despite the occasional weak fibril development present in *S. rubellum* stem leaf hyaline cells. This category is likely composed of *S. fuscum* as this taxa is found only in Core I (a transitional region core) and *S. rubellum* is much more common in oceanic regions, being scattered and less common inland (Crum and Anderson 1981). *Sphagnum fuscum* is also the dominant bryophyte in the surface vegetation above the Core I peat and, as such, this category is referred to simply as *Sphagnum fuscum* in the text proper.

Sphagnum magellanicum

A *Sphagnum* species belonging to Section Sphagnum, and having the cucullate-concave branch leaves and spiral fibrils reinforcing branch and stem cortical cells, typical of the section. Chlorophyllous cells of branch leaves, in cross-section, short-elliptic and entirely included, exposed on neither ab- nor adaxial surface.

Sphagnum magellanicum / centrale

A grouping of *Sphagnum* species belonging to Section Sphagnum and having the cucullate-concave branch leaves and spiral fibrils reinforcing branch and stem cortical cells, typical of the section. In both species the chlorophyllous cells of branch leaves, in cross-section, are elliptic and poor sample preservation resulted in uncertainty as to whether these cells were not (as *S. magellanicum*) or slightly (as *S. centrale*) exposed on both the ab- and adaxial leaf surfaces. Since *S. magellanicum* is identified, with certainty, in other samples, this grouped category likely represents poor preservation of *S. magellanicum* and not the presence of *S. centrale*, which was not identified, on its own, elsewhere in the study.

Sphagnum papillosum

A *Sphagnum* species belonging to Section Sphagnum, and having the cucullate-concave branch leaves and spiral fibrils reinforcing branch and stem cortical cells, typical of the section. The chlorophyllous cells are narrowly truncately elliptic, trapezoidal or ± triangular, in cross-section and exposed ± equally on both surfaces, or more broadly on the adaxial leaf surface. This species, in particular, is characterized by fine, dense papillae on the inner wall of branch leaf hyaline cells.

Sphagnum teres

Belonging to Section Squarrosa, and distinguished from other species of *Sphagnum* by the ovate-lanceolate to linear (1.0 – 1.5 mm long), non-cucullate branch leaves with chlorophyllous cells narrowly triangular to trapezoidal in cross-section and more broadly exposed on the outer (abaxial) surface. Branch leaves have numerous large (often ≥ ½ the cell width), rounded, unringed pores on both the ab- and adaxial surfaces, while stem leaves are lingulate, and fimbriate across broadly rounded apicies.

Sphagnum warnstorffii

A species belonging to Section Acutifolia, distinguished from other members of the section by the lack of pores on the stem cortical cells (if present) and by the small (≤ 2 μm) strongly ringed pores on the upper portions of the abaxial branch leaf cells. These small, ringed pores are abruptly differentiated, about half way down the leaf, from the large, ovate pores occurring in the lower and side portions of the abaxial branch leaf surface.

Other Mosses

Aualcomnium palustre

An acrocarpous moss with stems covered in numerous, brown rhizoids. Leaves are lanceolate to narrowly lingulate, with a costa ending somewhat below the leaf apex. Leaf margins are entire and recurved below but often irregularly serrulate towards the apex. Leaf cells are approximately isodiametric and strongly unipapillose, retaining a yellow – green hue even in macrofossil samples. Basal cells, in contrast, lack papillae, are multistratose and often somewhat elongate and enlarged, pale with brownish cell walls.

Bryum sp.

An acrocarpous moss with ovate to elliptic or broadly lanceaolate leaves. Leaves are bordered by narrow, elongate cells, while median cells are smooth, and rhomboidal to hexagonal, with a length to width ratio usually less than 4:1. Samples from this study were likely sterile forms of *Bryum pseudotriquetrum* and had thick - walled leaf cells, decurrent leaf bases, and margins slightly serrulate towards the apex, with an excurrent costa.

Calliergon giganteum

A robust, pleurocarpous moss, with regularly pinnate branching and stem leaves crowded toward the apex, forming distinctive, cuspidate tips. When in-tact plant fragments aren't present, this species is easily identified by large (1.3 – 3 mm long), decurrent stem leaves that are broadly cordate – ovate, with cucullate tips, entire margins, abruptly inflated alar cells, and a strong single costa extending ¾ or more the length of the leaf. Median leaf cells are smooth and linear.

Calliergon trifarium

Simple or sparsely branched, with tightly imbricate leaves, this species is found in macrofossil samples as julaceous fragments with leaves still attached to the stem. Having the smooth, oblong-linear median leaf cells typical of the genus, *C. trifarium* is characterized by concave, almost round leaves (1-2 x 1-1.6 mm) with obtuse apicies and a thin costa, extending only from ½ to ¾ of the leaf length. Leaf bases are not decurrent and the firm walled, oblong alar cells are neither inflated nor abruptly differentiated.

Dicranum sp.

An acrocarpous moss, characterized by linear – to ovate – lanceolate, falcate – second leaves and a well-developed costa (occupying <1/3 of the leaf base), with central guide cells and 1-2 stereid bands. Alar cells are inflated in orange to brown groups and stems are commonly matted, especially below, with white or reddish brown rhizoids. Leaves are generally erect with bases imbricate along the stem and falcate - secund tips diverging. In macrofossil samples, often the divergent leaf tips are lost or very poorly preserved, preventing identification to a species level.

Drepanocladus sensu lato

Although current taxonomy subdivides *Drepanocladus* into six genera (one of which is a still named *Drepanocladus*, but with fewer species), the broad concept of *Drepanocladus*, as used by Wynne (1944) and Crum and Anderson (1981), among others, is still a useful grouping, particularly with macrofossil material, where leaf tips, leaf margins, and stem cross-sections may be difficult to obtain. *Drepanocladus* sensu lato is characterized, primarily by falcate-secund to circinate leaves, with strong, single costae, extending to, at least the upper half of the leaf, and long, linear median leaf cells. One variety (*Drepanocladus aduncus* var. *kneiffii*) does, however, violate this pattern, being a straight-leaved expression of an otherwise falcate-secund species. Individual species of *Drepanocladus* sensu lato are characterized as having entire, or serrulate leaf margins, plicate or smooth leaf surfaces, and alar cell groups ranging from undifferentiated to inflated in well-defined groups. The stem cross-section is also used to identify species based on the presence or absence of a central strand of smaller, differentiated cells, and by the presence or absence of a layer of enlarged, thin-walled stem cortical cells (hyalodermis).

Drepanocladus aduncus

Differentiated from other species of *Drepanocladus* sensu lato by the abruptly inflated, thin-walled alar cells, in clearly-defined groups, not reaching to the costa, and by the stem cross-section lacking a hyalodermis, and with a central strand present but weakly developed. Leaves are ovate-lanceolate, usually falcate-secund, although occasionally straight in var. *kneiffii*, with a slenderly acuminate, entire apex, and a single costa ending in the upper part of the leaf. Leaf cells average from (17) 51-64 (120) µm long by 6 µm wide, in leaves (1.2) 2.3-2.8 (6.3) mm long.

Drepanocladus revolvens (*Limprichtia revolvens*)

Differentiated from other species of *Drepanocladus* sensu lato by non-plicate leaves, with entire margins (except occasionally in the apex of young leaves), and stem cross-sections identifying the presence of both a central strand and a hyalodermis. In the macrofossil samples, thin-walled cells of the hyalodermis are seldom preserved but locations of the missing hyalodermis cells can be seen as "c" shaped indentations in the underlying, thick walled cells. The circinate to strongly falcate-secund, ovate-lanceolate leaves are (1.4) 2.1-2.6 (4.6) mm long with a slenderly acuminate, flexulose apex and a single costa reaching to the upper half of the leaf. Upper leaf cells are long [(34) 51-69 (130) µm x 5 µm], with relatively thick, porose walls, while alar cells are inflated, and clearly differentiated in very small groups, with a maximum of 2-5 cells.

Drepanocladus vernicosus (*Hamatocaulis vernicosus*)

Differentiated from other species of *Drepanocladus* sensu lato by the lack of both a central strand and hyalodermis. Commonly seen with pinnate branching, even in fossil fragments, falcate-secund to circinate leaves from 1.5-2.5 mm long, distinguish this species from *D. lapponicus*, the only other species of *Drepanocladus* sensu lato to lack a central strand. The lack of differentiated alar cells also help to distinguish this species from *D. aduncus*, which has a weakly developed central strand that is occasionally difficult to identify in macrofossil material. Leaf margins are entire, and upper leaf cells elongate [(31) 41-73 (75) µm x 5 µm] with either thin or thick, porose cell walls.

Hylocomium splendens

A robust, pleurocarpous moss, clearly distinguished by the bipinnate to tripinnate branching pattern with each year's growth arising from the middle of the previous year's in a characteristic "stair-step" pattern. The branching pattern of the wiry, red stems is characteristic, even if the leaves are poorly preserved or missing. When present, stem leaves are 1.8 – 4 mm long, ovate-oblong, or ovate-lanceolate, and abruptly acuminate, with a double costa less than 1/3 to nearly ½ of the leaf length. Leaf margins are serrulate often to the base, and long, narrow (30-50 x 4-6 µm) median leaf cells are usually papillose by projecting cell ends. Although basal cells are shorter and broader than median leaf cells, with thick, pitted walls, alar cells are not differentiated. Branch leaves are slightly smaller, but similar to stem leaves and branched paraphyllia are abundant on both stems and branches.

Meesia triquetra

An acrocarpous moss with strongly 3-ranked leaves squarrose-spreading from an erect base. Leaves are 2-3.6 mm long, triangular-lanceolate, and serrate nearly to the base. The costa occupies less than 1/3 the leaf width at the base and ends near the apex. Leaf cells are non-papillose and rectangular to hexagonal with walls somewhat thickened. A distinctive dark green to yellow-green colouration is preserved in the leaf cells even in deep peat samples.

Moss

This category includes those samples where remains were identified as a moss, with costate leaves and a unistratose lamina. Poor preservation, however, resulted in no in tact leaves and the sample could not be identified to species.

Pleurozium schreberi

A robust pleurocarpous moss, with red stems and irregularly singly-pinnate branching. Leaves are imbricate along the stem, and broadly ovate to elliptic or oblong-ovate (2-2.8 x 1-1.5 mm), and concave, with a rounded apex, often appearing apiculate because of in-rolled margins. The leaf margins are entire, the costa is short and double, or lacking, and the smooth, median leaf cells are long (50-80 x 6-8 µm), and linear. Cells at the insertion are shorter, thick walled, porose, and orange, with clearly differentiated alar cells, yellow to brown and quadrate, or somewhat inflated in small, triangular groups. Paraphyllia are lacking and branch leaves are similar, or smaller than stem leaves. Poorly preserved specimens, containing only red stems, can be differentiated from *Hylocomium splendens*, by the singly pinnate branching pattern.

Polytrichum strictum

A stiffly acrocarpous moss with lanceolate to linear-lanceolate leaves, erect- to wide-spreading from a sheathing base. Entire margins are incurved above the sheathing base, folding over the broad costa and enclosing the 25-30 lamellae running longitudinally down the ventral face of the costa. The costa is excurrent as a reddish, serrulate awn and stems are often matted with numerous whitish rhizoids. In poorly preserved samples much searching is often required to find a leaf tip to confirm the species identification as in many plants only the sheathing leaf bases remain on the stem.

Ptilium crista-castrensis

A robust pleurocarpous moss with very regular pinnate branching and falcate-secund leaves macroscopically visible as hooked branch tips. Stem leaves are broadly triangular-ovate, long-acuminate, and decurrent. Both stem and branch leaves are strongly plicate, with costae short and double or lacking, and margins serrulate above. Median leaf cells are smooth and long, linear-flexulose (50-100 x 3-5 µm) and basal cells are shorter and broader with walls somewhat pitted and alar cells undifferentiated.

Racomitrium sp.

A genus of fairly robust mosses distinguished by strongly sinuose-nodulose leaf cell walls. Material referred to this genus likely belongs to the species *R. lanuginosum* but poor preservation, namely the lack of leaf apicies, prevented positive identification to species.

Racomitrium lanuginosum

A fairly robust pleurocarpous moss distinguished by the strongly sinuose- nodulose cell walls, typical of the genus, and distinctive hyaline leaf apicies. The leaf apicies consist of a region of papillose, hyaline cells extending throughout the hairpoints and decurrent down the margins of the leaf-proper. Knot-like teeth extend along the leaf margins throughout the hyaline region. Leaves are 3-4.6 mm long, lanceolate to ovate-lanceolate, often falcate, with a single costa extending into the hyaline apex. Leaf cells are not papillose, except in the hyaline apicies,

Scorpidium scorpioides

A rather large, lax, pleurocarpous moss, with leaves loosely imbricate and often falcate towards branch tips. The leaves are large (2-4 x 1.4-1.8 mm), ovate-lanceolate to oblong-lanceolate, concave, with the costa short and double or lacking, and margins entire, or faintly serrulate towards the apex. Median leaf cells are smooth, long and narrow (75-110 x 6-7 µm), with shorter, pitted basal cells and a few somewhat inflated alar cells with thinner walls. These large, lax leaves are rarely preserved in their entirety in macrofossil samples, and are often found as "shredded" leaf fragments attached to the stems.

Tomentypnum nitens

A robust, pleurocarpous moss with irregular, pinnate branching, and brown rhizoids commonly matting the underside of the stem and leaf bases. Leaves are elongate-lanceolate, with entire margins, and are deeply plicate, often obscuring the narrow single costa which extends ¾ to 4/5 the leaf length. Median leaf cells are thick-walled, long, and narrow (50-90 x 5-6 µm), with basal cells shorter, and broader with pitted walls and no differentiation of alar cells, and non-decurrent leaf bases.

Liverworts

These taxa were only evident in the upper few samples (20 cm) of the cores and even at such shallow depths were generally poorly preserved. While it is likely that many surficial peatland communities included these species, rapid decomposition has prevented them from being preserved in the macrofossil record of any but the most shallow samples.

Calypogeia sphagnicola

A relatively small [(0.5-) 1.5-1.8 (-2.0) mm wide] liverwort species characterized by incubous leaf arrangement, and rhizoids confined to sharply delimited regions of the underleaf bases. Leaves are obliquely ovate to ovate-triangular, widest basally with an entire, subacute apex, and attached at a 40-60° angle from the shoot apex. Underleaves are suborbicular and 1.2 to 1.8 x as wide as the stems, bilobed for approximately ¾ of their length, with acute or subacute, narrowly triangular or ovate-triangular lobes. Occasionally a single tooth is present on one of the underleaf lobes. Schuster (1969) keys this species partially based on leaf cell size, with marginal cells of the leaf apices 23-32 µm and median leaf cells averaging 30 x 38 µm.

Cephalozia loitlesbergi

A small [600-800 (-1000) µm wide] liverwort species characterized by succubous leaf arrangement, with alternate leaves very obliquely inserted, often strongly decurrent, and bilobed for approximately half their length. Leaves are entire, and have a narrowly lunate sinus and connivent lobes. Attenuate lobe apices, terminate in 2-3 frequently elongated, superposed cells, often resulting in cruciate lobe apices, especially in juvenile leaves. Underleaves are lacking.

Kurzia sp.

A small, pinnately branched liverwort genus characterized by stem leaves transversely inserted, and deeply 3-4 lobed. Lobes are 2-4 cells wide at the base and biseriate to within 1-3 cells of the apex. Basal leaf portions, below lobes, consist of 1 to 4 tiers of cells. Stems are only 4-8 cells wide in cross-section, and lack a hyalodermis. Underleaves are present as similar, or reduced forms of the main stem leaves. Species of this genus are not reliably separated by vegetative characters alone and no fertile material was found.

Mylia anomala

A relatively robust (2.4-3 mm wide) liverwort species characterized by succubous leaf arrangement, with alternate, entire, orbicular (1450-1750 µm wide x long) leaves. Leaves are shortly decurrent dorsally, and spreading to erect-spreading, appearing crowded and nearly erect at branch tips. Leaf cells are large (apical and mid leaf cells 45-50 x 50-60 µm), with prominent, bulging trigones and a smooth cuticle. Relatively large (up to 680 x 300 µm), lanceolate to narrowly lanceolate underleaves are often obscured by dense rhizoids arising from both underleaf and ventral leaf bases, as well as scattered on the stem surface.

LICHENS

As with the liverworts, these taxa were only found in the uppermost sample (7 cm) of a core and even at such a shallow depth were poorly preserved. While current surficial peatland communities include these species, rapid decomposition has prevented them from being preserved throughout the macrofossil record.

Cladonia / Cladina

These taxa were characterized by particularly poor preservation and, so, were unable to be identified even to the genus level. Generally preserved as white mats of hyphae, the only structure evident was that of hollow stalks characteristic of both *Cladina* and some species of *Cladonia*.

VASCULAR PLANT REMAINS

Macrofossil remains in this category are very small in size relative to the entire organism and, as such, cannot be identified by standard keys. A number of references designed for use with macrofossils were exceedingly useful and are listed below. Most remains, however, were identified based on a combination of personal experience and familiarity with the species concerned, coupled with extensive sampling of plant fragments, both above and below ground, from existing surficial communities in and around the peatlands studied. Standard identification guides were also used for detailed descriptions of specific plant parts once options had been narrowed down. In particular, Cyperaceae seeds are depicted in standard floras and field guides. A number of guides well suited for use with vascular macrofossil remains are listed below:

Lévesque, P.E.M., Dinel, H., and Larouche, A. 1988. Guide to the identification of plant macrofossils in Canadian peatlands. Research Branch, Agriculture Canada Publication No. 1817.

Berggren, G. 1969. Atlas of seeds and small fruits of Northwestern-European plant species with morphological descriptions. Part 2 Cyperaceae. Swedish Natural Science Research Council and Berlingska Boktryckeriet, Sweden.

Berggren, G. 1981. Atlas of seeds and small fruits of Northwestern-European plant species with morphological descriptions. Part 3 Salicaceae – Cruciferae. Swedish Museum of Natural History and Berlings, Arlöv, Sweden.

Farrar, J.L. 1995. Trees in Canada. Fitzhenry & Whiteside Limited and the Canadian Forest Service, Natural Resources Canada, in cooperation with the Canada Communication Group – Publishing Supply and Services Canada.

Trees and Shrubs

Betula sp. Seed

Betula fruit are one-seeded nutlets, each with two membranous, lateral wings and two stigmas. This species is only likely to be confused with *Alnus* spp., which have narrower, corky wings. Excluding the wings, *Betula* nutlets are obovate or elliptic, with base and apex usually tapering. The wings may be 1 to 3 times as wide as the body and, including wings, the fruits measure 0.9-3.0 mm high, 0.7-1.8 mm wide, and 0.2-0.6 mm thick.

Dicot leaf fragments

This category is composed of leaf fragments with reticulate venation, except for those of *Ledum groenlandicum* which could be identified to species. This category is most likely composed of *Betula* and *Salix* leaf fragments, possibly with ericaceous species if only small portions of the leaves were preserved.

Empetrum nigrum

This category was identified based on leaves or leaf fragments. Linear, or narrowly triangular-ovate, entire leaves range in size from 3-7 mm long and superficially look rather needle-like. Upon close examination, no rows of stomata are present and the leaves entirely lack markings on the upper surface but are deeply grooved beneath due to infolded leaf margins. While the true leaf margins are infolded and not visible without dissection, the apparent leaf margins are, in fact, a sharp fold in the lamina, occasionally roughened as with minute serrulations. Leaves of this species could be confused with those of three, mostly alpine to subalpine species, but leaves of *Phyllodoce empetriformis* and *P. glanduliflora* are longer (up to 1cm), while those of *Cassiope stelleriana* do not have a groove on the lower leaf surface.

Ledum groenlandicum

The distinctive dense, glandular-woolly hairs which coat the young stems, bud scales, bracts, fruiting stalks, capsules, and undersides of leaves, make a large number of structures immediately identifiable. Stems are also identifiable with leaf scars usually raised slightly above the plane of the branch, and having a single, large, central vascular bundle scar. The leaf scars range in shape from late season growth when they are broadly heart shaped or rounded and approximately equilaterally triangular, to early season growth when short internodes, result in very broadly triangular to almost lenticular scars. Often, even on older branches, there is some hint of sparse, glandular hairs.

Oxycoccus microcarpus

This category was identified based on leaves or leaf fragments. With sharply acute or apiculate leaf tips, due in part to the inrolled margins, these leathery leaves preserve fairly well in the peat matrix and can be distinguished from the rounded, or bluntly acute leaf tips of *Vaccinium vitis-idaea*. Both species have similarly sized leaves (0.6-1 cm for *O. microcarpus* vs. 0.4-1.2 cm for *V. vitis-idaea*) but leaves of *O. microcarpus* are narrowly oblong while those of *V. vitis-idaea* are more broadly oblong to obovate, with less strongly inrolled margins. Lévesque et al. (1988) indicates that the petioles of *O. microcarpus* (= *Vaccinium oxycoccos*) are curved and offset with respect to the major axis of the leaf but I have not found this to be a consistent character, although, quite commonly the leaves do exhibit a slight curvature and associated offset petiole.

Picea mariana

As a genus, *Picea* species can be easily identified by the four-sided needles (somewhat flattened in *P. sitchensis*), which lack a petiole and are directly jointed at the base with leaf-pegs, remaining attached to the branches. Specifically, *P. mariana* has short (8-15 mm), stiff, straight needles with distinctly blunt pointed tips, and four stomatal regions, occupying the grooves to either side of a thickened, central axis. The two stomatal regions on the ventral surface are more prominent, each consisting of approximately three rows of stomata, while regions on the dorsal surface often only contain a single stomatal row each. *P. mariana* cones are also distinctive. As a whole, the cones are short (2-3 cm), tightly imbricate, and broadly ovoid, while individual scales are broadly concave, and obovate to almost circular, with a semi-circular, irregularly toothed apex.

Pinus sp. leaf

Lacking the thicker, waxy cuticle, of *Picea mariana*, leaves of *Pinus* species do not preserve as well in the peat matrix. In the better preserved specimens, needles were identified from as spongy fragments, approximately 1.5 mm wide, with numerous, evenly spaced stomatal lines, along all sides of the fragment, semi-circular in cross section. In all needle fragments where it was possible to determine the cross-sectional shape, the specimen was identified as a two–needle pine, with a half-circle section, making *Pinus contorta* the specific identification. In poorly preserved specimens, however, the spongy texture, typical of *Pinus* was the only structure remaining, preventing specific identification in many cases.

Tsuga heterophylla leaf

Leaves are flattened (not four angled as in *Picea* spp.), with blunt, rounded tips, and two broad stomatal regions on the leaf underside, separated by a central groove. Each of the two ventral stomatal regions consist of approximately seven individual stomatal rows. The dorsal leaf surface has a much more shallow groove, not always evident in macrofossil material and no stomatal rows. The petiole attaches obliquely to the leaf, at an angle of approximately 10-40° from the main leaf axis. This is in contrast to *Picea* spp. where leaves attach directly to the branches with no petiole, and the slightly narrowed leaf base is in line with the main leaf axis.

Wood

This is a very general category, grouping together any woody fragments either too large or too poorly preserved to identify as belonging to an above ground (woody stem) or a below ground (woody root) plant part. This category also groups angiosperm and gymnosperm wood as often poor preservation made samples difficult to determine. Likely, most of this category is composed of wood fragments once belonging to large woody pieces either incorporated into the peat from coarse woody debris, or from structural roots of trees.

Woody root

Another general category including below-ground woody plant material. This category includes roots of both tree and shrub species growing on the peatland. Roots included here are mostly fine woody roots which would have most commonly occupied the upper, aerobic 20-40cm of peat.

Woody stem

This category includes woody remains identified as belonging to above-ground plant portions by leaf or bud scars. If leaf scars enabled more specific identification, those stems were allocated to the specific taxa (*Picea mariana*, or *Ledum groenlandicum*) rather than being included in the more general woody stem category.

Herbaceous Remains

Carex section Limosae roots

Identified as belonging to a group of three *Carex* species having roots covered in a yellowish felt. These roots may belong to any of *C. pluriflora*, *C. limosa*, or *C. paupercula* but *C. pluriflora* was identified as currently occurring in the surface peatland vegetation, and is the most common of the three species in coastal British Columbia, thus, is considered the most likely option.

Cyperaceae seeds

While the genus *Carex* is characterized by achenes enclosed within papery sacs (perigynia), in poorly preserved macrofossil samples perigynia are often lost and only achenes present. Most of the specimens included under Cyperaceae seeds were identifiable to the genus *Carex*, with perigynia approximately 2-8 mm long, elliptic to ovate, often tapering, or abruptly contracted to a beak at one end. Perigynia may be triangular to lenticular in cross-section and are often veined. In surface samples, 2-3 stigmas often protrude from the beak of the perigynium but are absent from macrofossil samples.

Eriophorum / *Trichophorum* seeds

Included in this category are small (approximately 2mm long) achenes, with long (at least twice as long as the achene) bristles attached to the base of the achenes. Both *Eriophorum* and *Trichophorum* species have such bristles, with *Trichophorum* having fewer but poor preservation often resulted in uncertainty as to the original number of bristles and the genera were grouped.

Fern sporangia (Polypodiaceae)

A line of specialized cells, extending in a "backbone" 2/3 of the way around a thin walled, spheroid, dehiscent vesicle, distinguishes a fern sporangium. The specialized, backbone cells, have unequally thickened walls, with thin outer walls and walls closest to the central vesicle substantially brown-red and thickened. This structure, which allows for unequal shrinking of the backbone cells upon drying, pulling open the vesicle and releasing spores, is microscopically distinctive.

Herbaceous remains

A broad category, consisting of any herbaceous material not clearly belonging to any more specific category and includes, mostly, roots from herbaceous species, excluding those of Polypodiaceae and *Equisetum*. Material is usually pale in colour, semi-transparent, and flattened. The majority of this category is likely composed of Cyperaceae roots.

Pteridophytae / *Equisetum* roots

Identification is based on photographs and keys to "Pteridophytae roots" given in Lévesque et al. (1988), coupled with microscopic examination of field collections of *Blechnum spicant*, *Dryopteris expansa*, *Pteridium aquilinum*, and *Athyrium filix-femina*. Pteridophytae roots are black, often shiny, with fine longitudinal ridges on the outer surface. In larger fragments, a central core of vascular tissue is often visible, consisting of yellow-orange strands, occasionally seen with regular lenticular markings. Unfortunately, the grouping "Pteridophytae" used by Lévesqye et al, (1988) is not clearly defined in botanical nomenclature (it is likely intended as the plural of the division Pteridophyta which includes, among others, the classes Polypodiales and Equisetales - the ferns and horsetails). This inclusion of *Equisetum* roots is further justified by the description of often shiny, reddish-brown to black, longitudinally striated *Equisetum* roots by Bauer (2002), In order to be clear that his grouping includes both the groups of Lévesqye et al, (1988) and Bauer (2002) this category was designated "Pteridophytae / *Equisetum* roots".

OTHER REMAINS

Chara sp.

This taxa was identified from oogoniums (organs where the female cells are formed in the Thallophytes e.g. Characeae) and specifically identified as belonging to the genus *Chara* based on photographs and keys given in Lévesque et al. (1988). A *Chara* oogonium may be recognized as a small (approx 0.5mm), solid, black, ellipsoidal mass with greater than eight fine helicoidal ridges adorning the surface, perpendicular to the main axis.

Charcoal

Black fragments, with a metallic sheen, which often maintain a blocky structure but crumble when pressure is applied with forceps or a dissecting needle.

Daphnia sp.

This taxa was identified from ephippia [protective capsules covering the fertilized ova of Cladocera (crustaceans)] and specifically identified as belonging to the genus *Daphnia* based on photographs and keys given in Lévesque et al. (1988). A *Daphnia* ephippium is recognized as a small (approximately 0.5 mm) thin, ovate-lanceolate structure, appearing as a white, translucent body, with (usually) two yellow-brown masses embedded within. Personally, I find it reminiscent of a fried egg with two yolks.

Debris

Perhaps more aptly described as fine grained organic debris, this category consists of highly decomposed, amorphous brown material in which no recognizable plant structure is discernable.

Marl

Only reliably identified in the macrofossil record when a substantial amount was present within a sample, marl can be described as opaque, white, amorphous material. Marl was occasionally noticed to have a gritty texture when abundant in a sample, but grains broken apart easily when crushed with forceps.

Mineral Soil

Identified as solid grey or white grains, not crumbling under pressure when squeezed with forceps.

Mollusc shells

Easily identified by the hollow, tapering spiral form, or classic bivalve "clam" shape when present in an undamaged form. The delicate, white shells are easily broken and are often found as fractured pieces visible only as white plates within a debris matrix. Usually, however, some entire shells are present in the same sample, making identification obvious.

APPENDIX IV

Detailed Macrofossil Diagrams

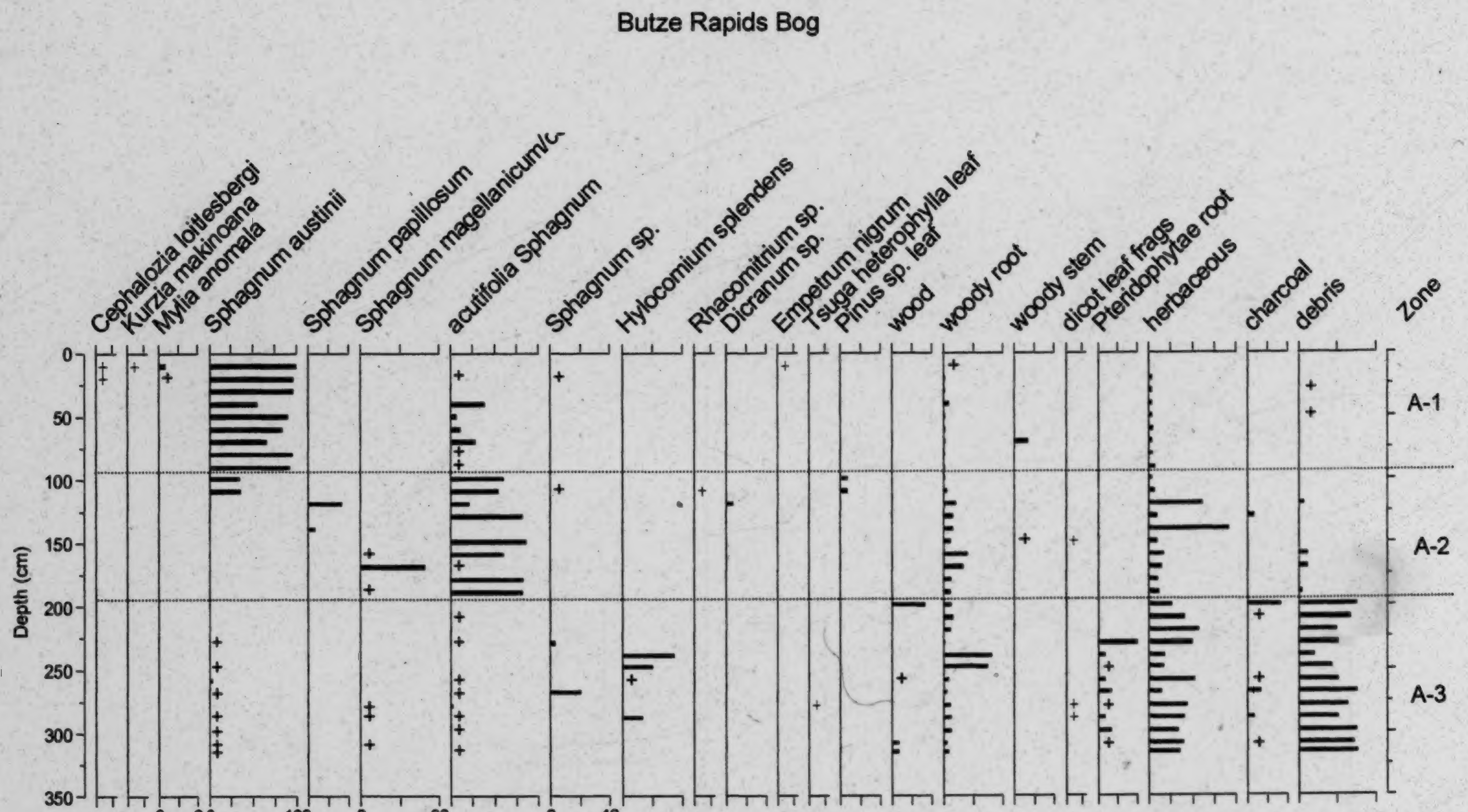

Figure A4-1: Detailed macrofossil diagram of Core A with core zones as delineated by constrained incremental sum of squares cluster analysis. The vertical axis represents the sample depth from the peat surface, with abundance (%) of different macrofossil taxa plotted along horizontal axes. Macrofossil abundances of < 1% are represented with a + sign.

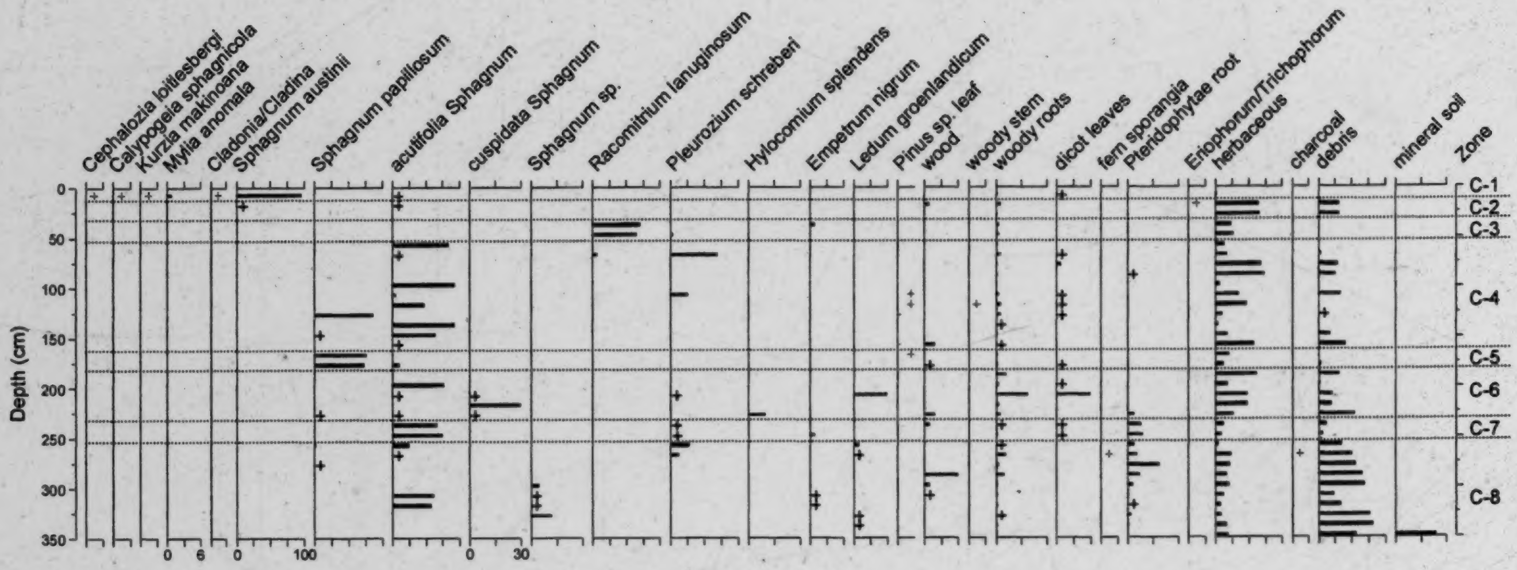
Green River Bog

Figure A4-2: Detailed macrofossil diagram of Core C with core zones as delineated by constrained incremental sum of squares cluster analysis. The vertical axis represents the sample depth from the peat surface, with abundance (%) of different macrofossil taxa plotted along horizontal axes. Macrofossil abundances of < 1% are represented with a + sign.

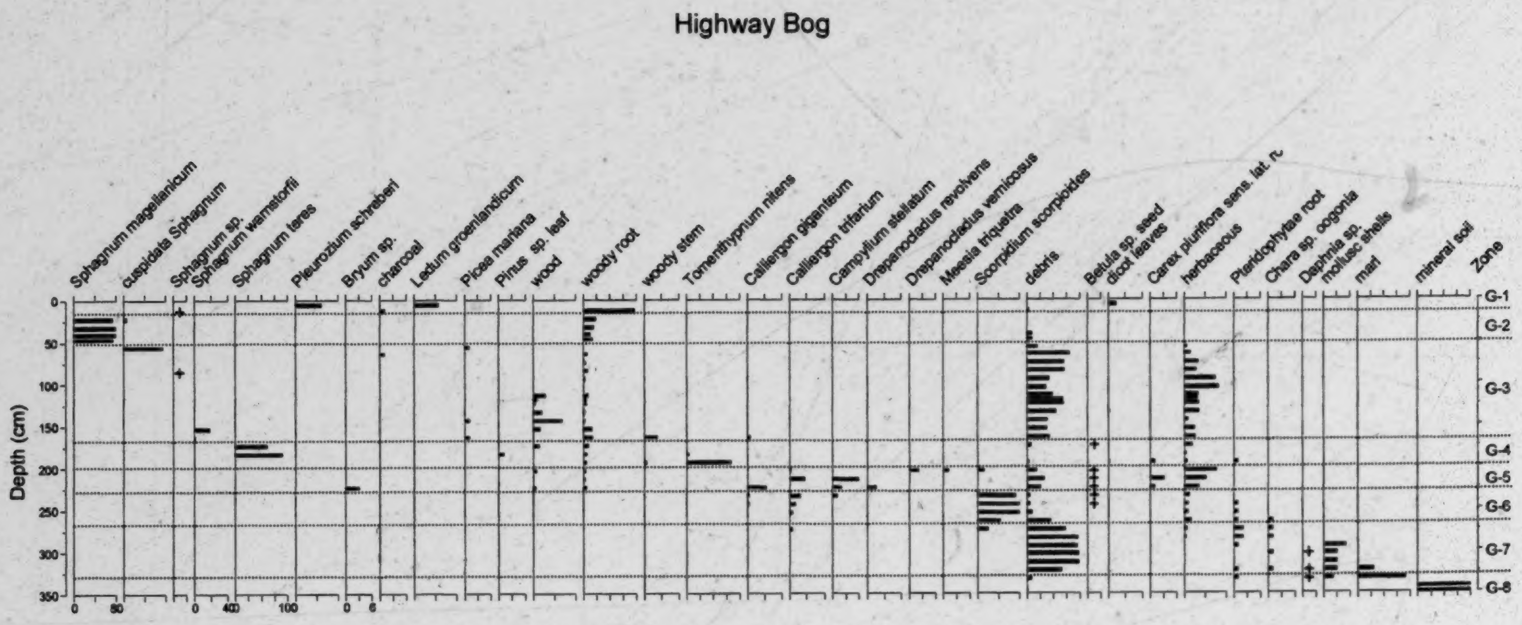

Figure A4-3: Detailed macrofossil diagram of Core G with core zones as delineated by constrained incremental sum of squares cluster analysis. The vertical axis represents the sample depth from the peat surface, with abundance (%) of different macrofossil taxa plotted along horizontal axes. Macrofossil abundances of < 1% are represented with a + sign.

Powerline Bog

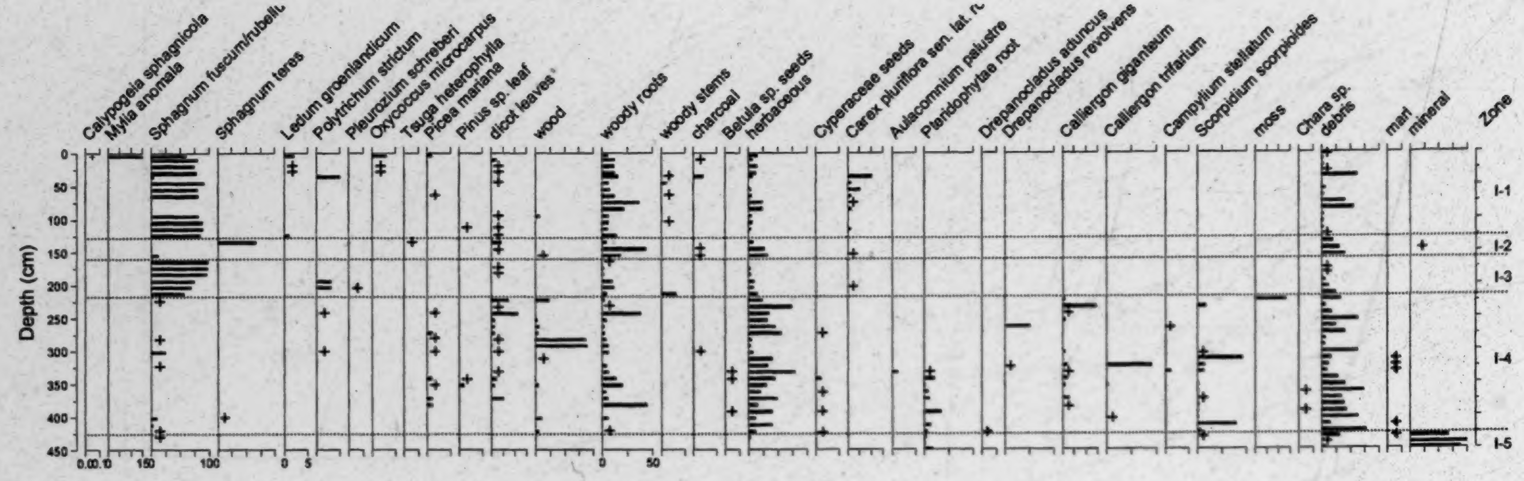

Figure A4-4: Detailed macrofossil diagram of Core I with core zones as delineated by constrained incremental sum of squares cluster analysis. The vertical axis represents the sample depth from the peat surface, with abundance (%) of different macrofossil taxa plotted along horizontal axes. Macrofossil abundances of < 1% are represented with a + sign.

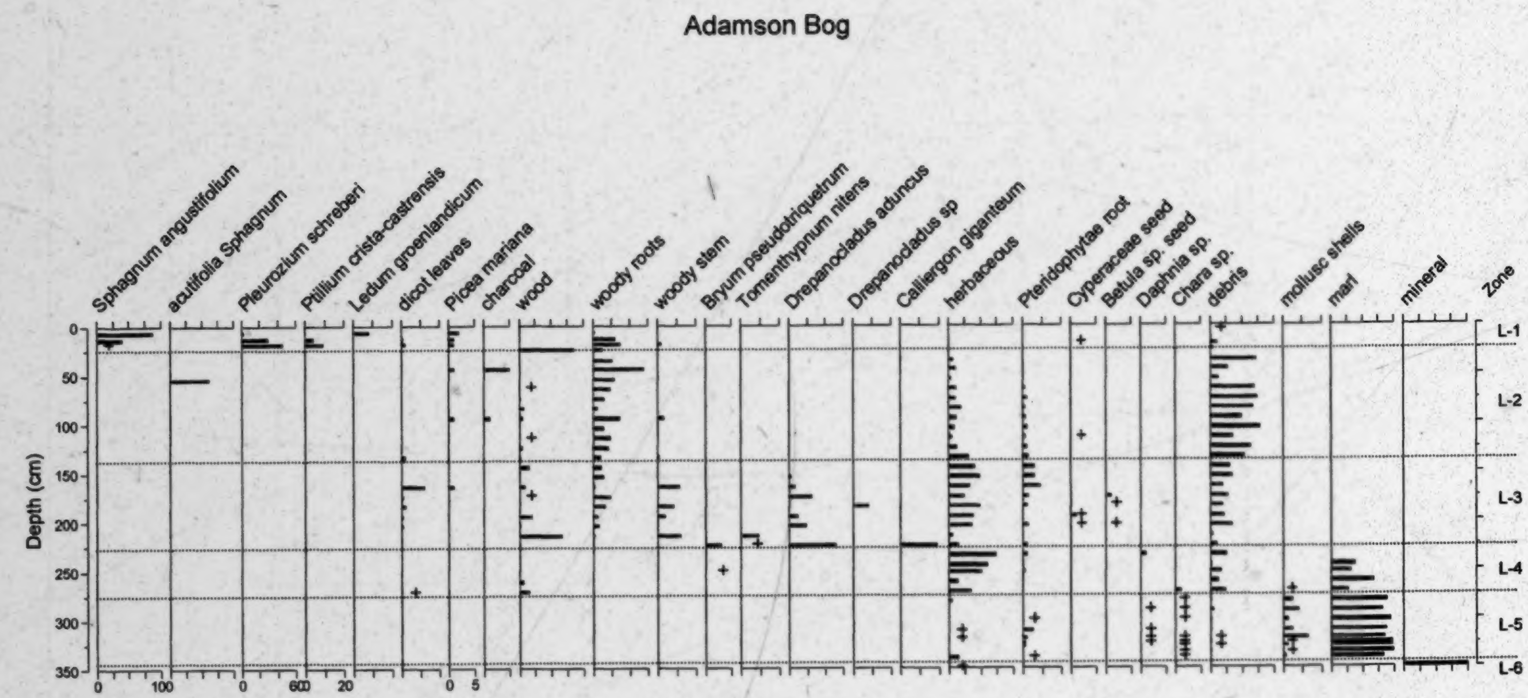

Figure A4-5: Detailed macrofossil diagram of Core L with core zones as delineated by constrained incremental sum of squares cluster analysis. The vertical axis represents the sample depth from the peat surface, with abundance (%) of different macrofossil taxa plotted along horizontal axes. Macrofossil abundances of < 1% are represented with a + sign.